THE PHYSIOLOGICAL MECHANICS OF PIANO TECHNIQUE

AN EXPERIMENTAL STUDY OF THE NATURE OF MUSCULAR ACTION AS USED IN PIANO PLAYING, AND OF THE EFFECTS THEREOF UPON THE PIANO KEY AND THE PIANO TONE

BY

OTTO ORTMANN

—

WITH NUMEROUS ILLUSTRATIONS

This book is a counterpart of the author's **The Physical Basis of Piano Touch and Tone** (1925), with which it shares a clear demarcation of problem and a comprehensive experimental procedure. Complex physiological movement, as applied in piano playing, is analysed into its components by means of photographs and records made under playing conditions. The results throw significant light upon many hitherto obscure phases of piano playing.

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The Physiological Mechanics of Piano Technique

An experimental study of the nature of muscular action as used in piano playing, and of the effects thereof upon the piano key and the piano tone

By
OTTO ORTMANN
Research Laboratory of the Peabody Conservatory of Music, Baltimore, Maryland

WITH NUMEROUS ILLUSTRATIONS

A counterpart of an earlier study on the Physical Basis of Piano Touch and Tone

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PREFACE

"ALLE Theorie ist grau." This Mefistofelian rejoinder of the philosophic Faust typifies, quite accurately, the usual attitude of the musician toward a scientific investigation of his art. The "whys" and the "wherefores" do not concern him; they are colourless superfluities, gray before the beginning, and, unfortunately, often gray after the investigation. He still believes that the single piano-key can be influenced in other ways than dynamically, and that a knowledge of the action of muscles and of the laws of the lever are of no value in his work. That is the typical attitude. A few eminent and praiseworthy exceptions tend but to emphasize the prevalent view.

This attitude is to be regretted. It has served to keep obscure a field of great theoretical interest and practical importance: the border-land where science meets art. True, a group of able workers has already made headway, not without some serious errors, in clearing away the obscurity: Tetzel, Steinhausen, and Breithaupt in Germany, Matthay in England, Jaell in France, Brugnoli in Italy; but their books, when they are found in the teacher's library at all, too often still have their leaves uncut. Translations, with one or two exceptions, do not exist; a rather lamentable reflection upon professional appreciation of really valuable original contributions to the field of physiological mechanics. The concert artist, if he so chooses, may work as he will, remaining his own problem, or, perhaps, finding his own solution; but the teacher, selling lessons in physiological mechanics hour after hour, day after day, should at least know the tools with which he works.

But, too often, he does not; and since he constantly uses his arms and fingers, he usually resents the assertion that he does not know how they are used. He will oppose *con ira* the use of any Latin anatomical term, but he will accept, *tranquillissimo*, many Italian terms, which, when applied to the piano, have no meaning at all. Relaxation, contraction, weight-transfer, coördination, looseness, mechanical forces, and force quality are bandied about in terminological confusion, and when he is told that many of the tonal effects are imaginary, that is to say, when he is confronted with scientific data, he usually resorts to a condescending sneer or to an infuriated, albeit blind disparagement, neither of which

in any way refutes the original findings or the conclusions to which they lead. When, in a previously published volume on the Physical Basis of Piano Touch and Tone, I deduced evidence of the utter dependability of piano tone-quality upon tonal intensity and duration, many of the letters and comments that reached me were thus delightfully logical or personally complimentary. I select three remarks, from many, as typical; the pious axiom: "The soul of the piano transcends all investigation"; the intelligent comment: "The records may all be true, but I do not believe them even if they are"; and the much more colourful motive: "You are crazy."

On the other hand, those teachers who, after a few hours' perusal of an anatomy proceed to lend their writings and teaching a pseudo-scientific basis by injecting, subcutaneously, a miscellaneous dose of Latin names, likewise have helped to obscure the field. I know of one instance where the muscles bending the nail-joints are described as situated in the fingers; another where a single muscle, the deltoid, apparently is responsible for all the variations of piano technique. The human organism is not quite so simply arranged. Only they who have seriously sought to unravel some of its intricacies can adequately appreciate the structural complexity and the functional wonders of the machine called man. Among these are the scientists and those musicians who realize the need for a scientific determination of data and the evaluation thereof in terms of the pianist's performance.

The present investigation of physiological mechanics was undertaken in order to establish, if possible, a sound physiological basis for the mechanics of piano technique. The experimental work connected with it has extended over a period of five years, a great part of which was given over to the necessary verification of data and to improvements in methods of recording. It is published as the second part of a general investigation of piano technique, of which the first part is the Physical Basis of Piano Touch and Tone already mentioned, and of which the third part will be a study, now in course of preparation, on the psychological phases of the problem. The interrelation among these parts must be kept in mind in interpreting the present results, because the limitations within which certain topics are here treated, are otherwise not commensurate with their relative importance. The present investigation is limited to the mechanics of muscular action, particularly of the movements used in piano-playing. Problems of coördination, in so far as they involve neural and cortical activity, are left untouched, or are treated fragmentarily, in order to keep the

study within its prescribed limits. In spite of this restriction, however, the line of demarcation often could not be precisely determined, and an occasional excursion into the interesting psychological field could then not be avoided.

The study, in spite of its limitations, has a three-fold value: a general theoretical value, in that it seeks to arrive at the true status of the operation of the muscles used in piano-playing, resting its case with the attainment of this aim, apart from all other considerations; secondly, a specific, practical value, in that it throws light upon concrete problems of piano technique, where its findings will aid piano teaching and playing; and, lastly, a cumulative value, in that it forms, in connection with the physical phases, a necessary basis for any investigation of the psychological aspects of the problem. Coördination, muscular memory, practice methods, learning curves, and allied questions cannot be intelligently analysed without a clear knowledge of their physiological and mechanical substructure; nor could the physiological phases have been adequately investigated without a knowledge of the purely physical attributes of piano touch and tone.

The experimental method of procedure was adopted in order to eliminate the vagaries of the personal equation. The subjects making the records were instructed to play as they normally would, knowing nothing about the aim of the experiment. Extreme care was necessary here, for the subtlety with which the mind affects movement may readily become a source of serious error. All records, therefore, were checked by repetition. An additional check is furnished by physiological and mechanical theory, with the laws of which the records must agree if they are to be considered valid.

Finally, I wish to acknowledge my sincere appreciation of the assistance given me through the many hours of tedious work. I am indebted to the late Harold Randolph and to May Evans for placing at my disposal an adequately equipped laboratory, to my colleagues at the Peabody Conservatory for their time and patience in making the records, and to Virginia Blackhead, Louis Cheslock, and Wilmer Bartholomew for assistance in the conduct of the experiments and in the organization of the data. To Dr. Max Kahn my thanks are due for the excellent Röntgenograms and for valuable aid in their interpretation. Also to Messrs. Longmans Green & Co., Ltd. for permission to reproduce Figures 17 and 18 from Gray's Anatomy.

O. O.

Baltimore,
January, 1929.

PART I
THE PHYSIOLOGICAL ORGANISM

Chapter I

Mechanical Principles

The complex problem of physiological mechanics as applied to piano technique resolves itself finally, into one basic question: the variations of force produced at the key-surface by the player. The present study is concerned with the manner in which these force-variations are produced.

Since the final end of all technical movements at the keyboard is this force-variation, the body becomes a machine, and, like all machines, must obey the laws of mechanical action. Action and reaction, equilibrium of forces, dependence of a force upon mass and acceleration, laws of the lever—all these apply to physiological motion as well as to mechanical motion in general. The fact that physiological motion is more complex, and is under the control of volition, does not introduce any new principle of reaction in the mechanical part of movement.

As basis of the investigation we have, first of all, certain fixed properties of matter which should be clearly differentiated.

Rigidity: that property of matter as a result of which its shape cannot easily be changed.

Plasticity: The opposite of rigidity. That property of matter which permits it to be moulded into various forms.

Elasticity: That property of matter which causes a body to return to its original shape after the forces responsible for its change of shape have ceased to act. Rubber and steel are elastic; clay and lead are inelastic.

Compressibility: That property of matter which permits a diminution of volume.

Expansibility: The opposite of compressibility. Water is non-compressible and non-expansible; air is both compressible and expansible.

Weight: The mass per unit volume of matter.

Inertia: That property of matter by virtue of which a body tends to remain in a fixed state, whether of rest or of motion, until acted upon by external forces.

As further basis we have certain proved laws of mechanical action. The form in which they are here stated was selected with a view toward their relationship to the problems of piano-technique.

1. A body at rest remains at rest unless acted upon by some external force.

2. A change in speed or in direction of motion of a body results from the action of a second force, the first force producing the original motion.

3. The total effect of a force depends upon three things: its numerical value, its direction, and its point of application.

4. The action of forces need not always produce motion. Two forces, equal and opposite, neutralize each other and do not produce motion.

5. The speed and direction of a body, unless the component forces be known, is not in itself an index of the forces acting upon the body. A force of 5 in the absence of all other forces will produce the same motion in a given body as a force of 10 opposed by a force of 5, other things equal.

6. The numerical value of a force depends upon the mass and the speed of the body producing it.

7. A force always produces motion in the exact line of its action, unless otherwise interfered with.

8. The force of gravity influences all motion. It acts vertically downward. Its value and direction are constant, the former for any given locality, the latter for all localities.

9. Motion that takes place along a straight line is called rectilinear motion; along a curved line, curvilinear motion. When a body turns upon any axis, real or theoretical, motion of rotation results. When a body as a whole changes its spatial relationship to surrounding bodies, motion of translation results. Both types of motion may be present at the same time, in equal or in unequal degrees.

10. A force whose effect is the combined effects of several other forces is called their resultant. The forces producing this resultant are called the components.

11. The mutual reactions of two bodies on each other are always forces equal in amount and opposite in direction.

Of the various types of mechanical work (lever, inclined plane, screw, wedge, wheel) we shall be primarily concerned with the lever.

Any rigid body capable of rotation about a fixed point or axis is a lever. The most useful form of the lever is a straight rod, in which the point or axis of rotation is called the fulcrum and the extent of rod on either side of the fulcrum is called the lever arm. Levers are divided into three classes.

Class 1.—Fulcrum between the force and resistance. In this class the force acts on one side of the fulcrum and the resistance to be overcome or the weight to be moved is on the other side of the fulcrum. The crow-bar, scissors, and the see-saw are examples. The characteristic feature of this class of levers is the change in direction between the line of force-application and that of resistance-motion. These motions (in the straight-rod lever) are opposite in direction. (Fig. 1*a*.)

Class 2.—Resistance between fulcrum and force. Here the fulcrum is at one end of the rod, the weight to be moved somewhere along the rod, and the force at some point between the weight

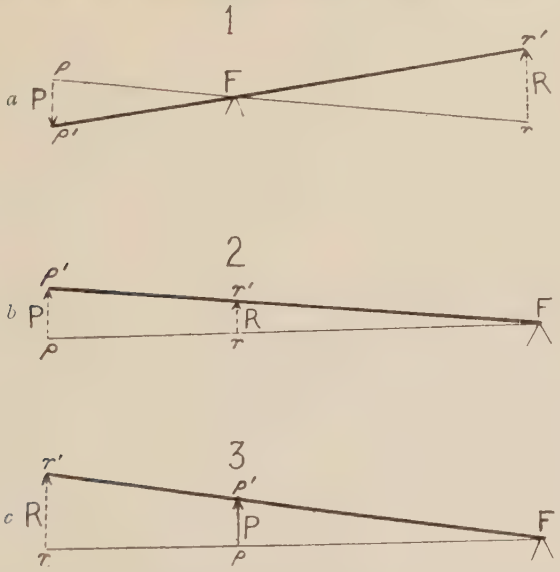


Fig. 1.

and the free end (not fulcrum end) of the rod. The wheelbarrow and the nutcracker are examples. The resistance is moved in the same direction in which the force acts. (Fig. 1*b*.)

Class 3.—Force between fulcrum and resistance. Similar to Class 2, except that force and resistance have changed places. The draw-bridge is an example. Direction of force and the movement of the resistance are the same. (Fig. 1*c*.)

The usefulness of the various types of lever is determined by the purpose which their application is to serve. The work-coefficient of all levers (ignoring friction) is the ratio of power-arm to resistance-arm. That is equivalent to saying that, since the work

done depends upon the weight moved and the distance through which it moves, the greater the distance, the less the weight; and, conversely, the greater the weight, the less will be the distance through which a given force will move it. The effect of this principle upon the three types of lever is shown in Fig. 1, *a*, *b*, *c*.

For class 1 levers this principle holds in any desired degree. By making F P long and F R short, a wide excursion of p to p' will result in a small excursion of R to R', but will enable P to lift a very considerable weight. The transfer is from speed to power. If F P be short and F R long, a slight displacement of P will cause a wide displacement of R, but with a corresponding loss of power. This is a transfer of power into speed.

The remaining classes of levers, on the other hand, are clearly differentiated in the mechanical purposes they serve. Since in Class II, R must always be between F and P, the power necessarily moves a greater distance than the resistance. Hence the use of such a lever always results in a gain in power with a loss in speed. In Class III the power always is between the fulcrum and the resistance. It must move through a distance less than the R. ($p' p < r' r$.) As a result we have always a gain in speed with a loss in force.

If speed in levers of the second class be desired, the necessarily wide excursion and excessive speed of the force-application would make the movement awkward. On the other hand, greater power can be secured with the third-class levers by appropriately increasing the power at P, which would not interfere with the practicability of the movement.

Points of application: One determinant of the value of a force is its point of application. By varying the ratio between the lengths of the lever arms (F R and F P) in any lever, the ratio between the force expended and the resistance overcome will be changed. In levers of the second and third classes, however, this change can never overcome their fundamental differences of function as to speed and force. The longer the power-arm, the more resistance can be overcome; the longer the resistance-arm, the more power will be required to move it.

Direction of force: A further determinant of the value of a force is its line or direction of application. It is greatest in power when the line of action is at right angles to the lever-arm, it diminishes in power as the angle of force-incidence decreases. When the angle reaches zero, the power-effect of the force upon lever-movement is zero also. That is

to say, when the line of action is parallel to the lever-arm, the force cannot act against the resistance to be overcome. The speed effect of a force is just the reverse of this : it is least when the force acts at right angles to the lever-arm and increases as the right angle of force-incidence decreases. These differences are shown in Fig. 2 for a third-class lever.

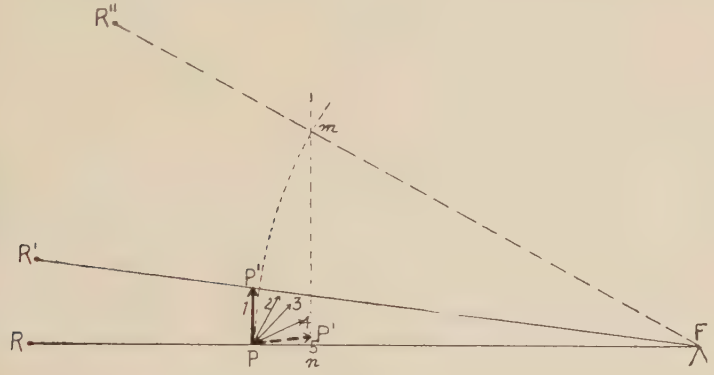


Fig. 2.

Direction 1 = greatest force, least speed ; direction 5 = least force, greatest speed. P P′ = distance through which power acts. R R′ R″ distance through which weight is moved. Since P P′ is the same for all directions, the difference in length between R R′ and R R″ shows the change in speed resulting from a change in direction of force. (P P′ may be assumed to be the distance through which a muscle shortens during a contraction.)

If a force the magnitude of which is represented by P P′ acts in direction 1, it will move R F into the position R′ F and the resistance R will move through R R′. If the same distance P P′ be applied in direction 5, in order to move P in direction 5 to P′, R F will have to move into position R″ F, because P F = m F, and m n is vertical. If, now, the distance P P′ be considered a shortening of the muscular tendon, equal amounts of contraction will produce the widely different displacements R R′ and R R″. The angle at which a muscle acts therefore helps to determine the work which a given contraction will do.

Combinations of these power, point, and direction relationships can produce any gradation of force-effects. If, to the maximum power-point position (levers of first and second classes), is added maximum direction-position (right angles to lever-arm), we get a lever producing the greatest amount of work when measured

by the resistance that it overcomes. And if, on the other hand, to the maximum speed-position (lever of the third class) is added the maximum direction-position (5 in Fig. 2), we get a lever giving the greatest speed. Between these extremes all grades of intermediacy are found. A force acting at a relatively unfavorable point in the lever-arm may overcome this disadvantage by acting in a proper direction. Or a force too weak to do the necessary work at one point, may be successfully used if it can be made to act at a more favorable point in the lever-arm. Equal end-effects may thus be attained in many ways by varying the relationships existing among the direction, the point of application, and the numerical value of the force.

The material point submitted to the action of a force is called the point of application of the force. The direction taken by the point as a result of this force-action, and considered independently of the action of other forces, acting simultaneously, is called the direction of the force.

The intensity of a force is measured by the velocity which it imparts to a given mass in a given unit of time. The greater the force, the greater the velocity.

A body at rest may be free from the action of forces or it may be acted upon by equal but opposite forces.

Two forces equal in intensity and opposite in their directions cannot produce motion. The forces, themselves, are not destroyed ; their external effects are neutralized.

Forces may be graphically represented by lines : the length of line corresponds to the intensity of the force and the direction of the line, to the direction of the force.

When a material point or system of points is acted upon simultaneously by more than one force, the movement imparted to it will be the algebraic sum of all the forces and their directions. This movement is called the Resultant ; and it can be produced by a single force of appropriate intensity acting in an appropriate direction.

Thus if a force of 4 acts on a body in one direction and a force of 2 acts upon it at the same time in an opposite direction, the body will move in the direction of the greater force at a velocity of $4 - 2$ or 2. The same motion will result from a single force of 2 acting in the given direction. The separate forces acting in producing a resultant are called its Components.

Parallelogram of Forces.—If a material point is acted upon by two forces represented by straight lines, both in magnitude and

direction, the resultant will be exactly represented by the diagonal of the parallelogram of which the two lines are sides.

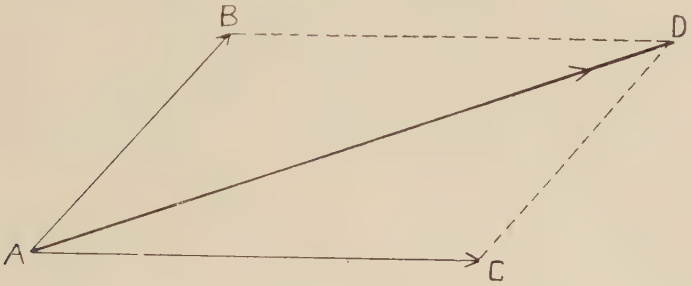


Fig. 3.

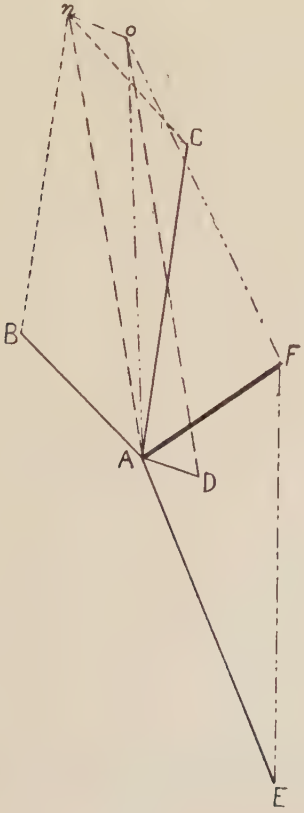


Fig. 4.

Let A B and A C be the two forces, acting upon point A. Their combined action will be represented in direction by the direction of the diagonal A D, and in intensity by the length of this diagonal.

Composition of Co-planar Forces.—The principle of the parallelogram of forces may be applied to the composition of any number of co-planar forces, by taking each two forces in turn and finding their resultant, which is then combined with one of the remaining forces to find a further partial resultant. When the last partial resultant has been combined on the parallelogram principle with the last single force, the resulting diagonal will be the total resultant of all the forces.

Let A be a point acted upon by four forces in one plane, their magnitudes and directions being represented by the lines A B, A C, A D, and A E respectively. The partial resultant of the forces A B and A C will be A *n*; that of the forces A *n* and A D will be A *o*; and finally that of the forces A *o* and A E will be A F. The total result of the action of the four original forces A B, A C, A D, and A E is therefore represented by a force of the magnitude and direction of A F. And a single force of this magnitude and direction acting upon A would produce exactly the same effect upon A as the combined action of the four given forces.

Parallelopiped of Forces.—When three forces acting upon a point are not co-planar, the resultant is the diagonal of the parallelopiped of which the forces are sides. Similar results are obtained for any number of forces.

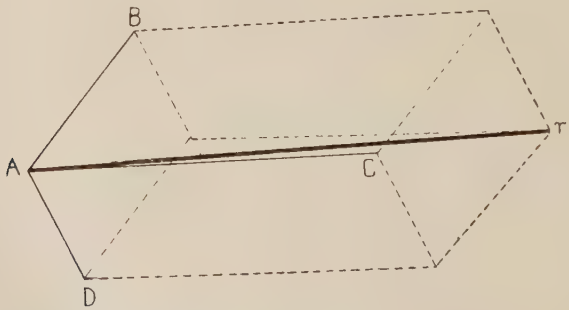


Fig. 5.

Let A B, A C, and A D be forces acting upon A. Their total resultant is A *r*.

Parallel Forces.—When two parallel forces are applied at the extremities of a straight line, they have a resultant equal to their sum and acting at a point which divides the straight line into parts inversely proportional to the forces.

Let A D and B E be two parallel forces acting upon the line A B. Their resultant will be represented in direction and magnitude by C R. A C : B E :: B C : A D.

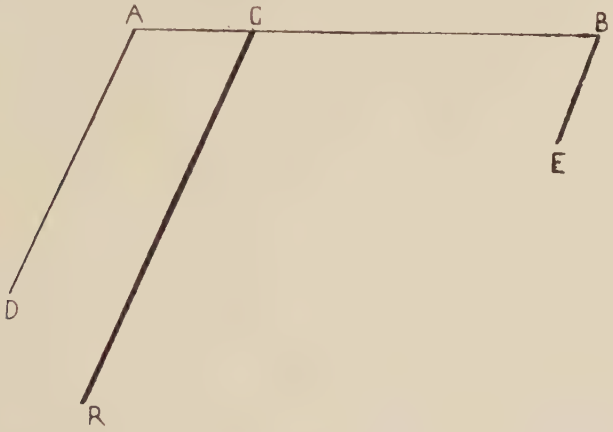


Fig. 6.

When the two forces are parallel but opposite in direction, their resultant will still be parallel to the components, but its magnitude will be equal to the difference of the components instead of their sum ; and the force will still act at a point in the straight line dividing the line into segments inversely proportional to the forces.

Composition of Parallel Forces.—The resultant of more than two parallel forces is compounded in a manner similar to the composition of non-parallel forces. Two forces are taken in turn and their resultant is then combined with one of the remaining forces.

The Couple.—A system of forces equal in magnitude and opposite in direction, acting at two points, not in the line of force, is called a couple and tends to produce rotation, in place of translation. Therefore, when a body possesses both translation and rotation we may assume the translation to be produced by a force and the rotation by a couple. The perpendicular distance between the lines of action of the two equal forces is called the arm of the couple. The product of one of the two equal forces and the arm is called the moment of the couple and is the measure of the power of the couple to produce rotation.

Resolution of Forces.—As any number of forces can be compounded into a single force, so a given force can likewise be resolved into two or any number of forces which would produce the same effect.

These mechanical principles thus stated, seem to have nothing to do with piano-playing. Yet when we recall that they operate in precisely the same mechanical manner from the playing of a simple finger exercise to that of a Beethoven sonata, we can appreciate them as the foundation for any investigation of piano technique. Consequently, they will be referred to frequently in the later analyses of physiological movement.

A few concrete instances will show this application :—

The principle of the lever points out the fallacy of locating the muscles that move a part in the part moved : finger muscles in the fingers, muscles that move the hand, in the hand, and so on. This is mechanically impossible.

The direction relationships explain the great speed obtained in arm, hand, and finger movements with relatively little muscular contraction, since most muscles are levers of the third class, acting in the maximum speed-direction (5, Fig. 2).

The composition of forces shows why the visual aspect of movement is not a safe guide to the muscular causes of the movement, since this may result from a few or many components.

The couple gives us a mechanical basis for the important fore-arm rotation touch.

These points and their manifold ramifications are taken up in detail in the subsequent chapters on Touch-forms.

CHAPTER II

The Skeleton

The Physiological Organism.—The human body is a highly integrated organism. A method, therefore, of disintegrated presentation is not without its palpable drawbacks. Chief among them is the premature drawing of inferences from the description of any separate part. Generalizations, or the application of a description of structure or function of any part to the movements of the body as a whole, must be postponed until the physiological mechanism has been studied in its entirety, for each part depends for its adequate practical use, to a great or small extent upon every other part.

The human body may conveniently be divided into four parts: the skeleton, the muscles, the nerves, and the circulation. The following description of each part is restricted to the presentation of material that has a bearing upon piano technique. This limitation and the resulting conciseness may occasionally give an erroneous impression of the simplicity or complexity of the total structure; the general conclusions, however, will hold in any case.

Skeletal Structure

The skeleton is the bony and cartilagenous structure that supports the fleshy parts of the body. It divides into two parts, the axial skeleton and the appendicular skeleton. The former embraces the skull, the spinal column, the breastbone, the ribs, and the hyoid bone; the latter embraces the bones of the upper and lower limbs. In piano-playing, as we shall see, the entire skeleton is used (pianos have been built to be played in a standing or even in a walking position so as to secure the greatest freedom); but, for the sake of clearness and brevity, only the bones and joints of the upper extremities will be considered in detail.

Not an inconsiderable part of piano pedagogy is concerned with the restriction of movements to certain joints, and on the other hand with the relaxation of joints, so that movement may be free. This restriction and freedom are directly dependent upon the anatomical possibilities of movement at the various joints, so that the following analysis of these possibilities, instead of having

mere theoretical interest, forms the basis upon which the analysis of the various touch-types of piano technique, described later, is built. A careful study of these movements will prevent much confusion as to what actually takes place muscularly when we play upon a piano, for without the skeletal structure, posture of any kind is impossible, and the skeleton, accordingly, is the true basis of all pianistic " positions ".

The Joint

A joint is the point at which two bones connect. Certain immovable joints, such as those in the skull, do not concern us here, since joints are of value to the piano teacher solely as potentialities for movement.

In any joint the essential feature is a sliding of one surface over another. Any such form of motion produces considerable friction. In healthy joints this is reduced by the interposition of two membranes, called synovial membranes (one for each articulating surface), between the bony surfaces, and by the constant moistening of these membranes by an albumen-like substance : the synovial fluid. This acts as a lubricant, and permits an easy, noiseless sliding of the two articulating surfaces.

Joined to the sides of the two bones, near their ends, and extending from one bone-head to the other, are ligaments, consisting of connective tissue. These ligaments, although they are plastic, so that they do not interfere with the movements at the joint, are, nevertheless, strong and inelastic. Strength and inelasticity are necessary if the ligaments are to fulfill their physiological function, which is the holding of the ends of the bones within the articulating cavity. If this normal range of movement be exceeded by tearing the ligaments, a dislocation of the joint may follow.

Since these inelastic ligaments must permit considerable natural movement at the joint, they cannot also serve to hold the bones in place during the range of natural movement. In these positions they surround the joint loosely, and only function actively when the movement reaches its physiological limit, at which position one of the ligaments (on the extended side) is fully stretched, and thus, being inextensible, makes further movement impossible, unless the ligament is torn (as, in a " sprain "). The function of holding the ends of the bones firmly together falls to the muscles controlling movement at the joint, and, more indirectly, to fat and fleshy parts of the body surrounding the joint. Atmospheric pressure probably also aids somewhat.

The particular action of the muscles is discussed in the chapter

on Muscles and Muscular Action. For the present it will suffice to point out their use merely as " stabilizers " of the joint. The latter is always surrounded by at least two sets of muscles, the one performing movement in a direction opposite to that of the other. In normal condition every muscle exerts a certain constant degree of pull, and this simultaneous pull on both sides of the joint presses one bone surface more or less firmly upon the other, making possible an immediate response to a nerve stimulus.

This analysis of joint-structure will form the basis for the later evaluation of the exercises devised by piano teachers for " loosening the joints ", many of which are not only useless, but actually injurious. In joint-structure we have the key to the effect of the stretch exercises, choice of fingering and, to some extent, control of tone.

The Elbow-Joint.—The Elbow-joint is a typical hinge-joint permitting movements of bending (flexion) and straightening (extension) around a single, approximately transverse, axis. Three bones enter into its formation, the large bone (humerus) of the upper arm and the two smaller bones (radius and ulna) of the fore-arm. Contrary to popular belief, no other movements than flexion and extension are possible at the elbow-joint. The pianistically important fore-arm rotation is not an elbow-joint movement.

Flexion at the elbow-joint, in which movement the hand is brought toward the shoulder or body, is usually limited by the contact of the fleshy parts of the inner (ventral) arm-surfaces at the elbow ; whereas extension is limited by the restraining effects of the ligaments and the muscles. The elbow-joint normally moves between 180° and 30° or 40°, from a position in which the whole arm is straight to the position of greatest bend at the elbow, with a consequent range of 140° or 150°. Movement at the elbow-joint permits movement of the hand in a one-dimensional plane only, with the elbow as its centre, and a central angle of 140° or 150.° Not until combined with movement in other joints, for example, in the shoulder, can this plane be shifted to any angle. In piano-playing most elbow movements are thus combined, and what is usually considered elbow movement entirely, involves other joints also.

The Radio-Ulnar Joint.—This is the articulation formed by the two bones of the fore-arm. The upper radio-ulnar joint (situated in the region of the elbow—but distinct from the elbow-joint), is a modified ball-and-socket joint which permits a turning of the fore-arm and hand palm-upward (supination) and palm-downward (pronation). This effect is produced by turning the radius

(the shorter of the two bones of the fore-arm) upon its longitudinal axis. When the arm hangs at the side of the body with the thumb of the hand forward (or palm upward when the fore-arm is horizontal), the two bones lie side by side, (Fig. 7*b*). In pronation, for example, when the hand is held in the normal hand-position of piano technique (Fig. 7*a*), the radius crosses diagonally over the ulna. The latter cannot rotate, and serves, with its connection to the large bone of the upper arm, to give the whole arm its continuity. Without the radio-ulnar joint, fore-arm rotation, upon which the important pianistic motions used in tremolo figures depend, would not be possible with any amount of freedom. Rotation could then come only from the shoulder; and it is this shoulder-rotation, and not the fore-arm rotation, that explains the apparent rotary movement of the ulna in a direction opposite to that of the radius.

The axis of fore-arm rotation extends through the head of the ulna in a line with the fourth finger of the extended hand, not the third finger. Fore-arm rotation normally takes place through an arc varying from 150° to 170°. Rotation beyond these limits results from the added 90° humerus-rotation at the shoulder-joint. Complete fore-arm rotation, therefore, if we include the coördination with the shoulder, can be extended through 260° or nearly three-fourths of a complete rotation.

Fore-arm rotation has an important effect upon the finger-movements used in piano-playing. The fingers, as appendages of the hand, can thus, without movement at their own joints, be made to descend and to ascend. Since the axis of rotation passes through the fourth finger, the thumb will describe the greatest arc because it is furthest removed from the axis of rotation, and the fifth finger, the smallest arc. The principle is illustrated in Fig. 11, and later, where tremolo movement is analysed. Movements used to shift this axis to the middle finger or other fingers are described under the wrist-joint.

The limit of pronation is set by the actual contact of the soft parts and the bones, and supination by the biceps muscle, the most powerful of the supinators. If the upper arm be permitted to hang freely vertically from the shoulder, and then the elbow be flexed to a right angle (the normal position for the pianist is this horizontal fore-arm), the hand will stand in a vertical, not horizontal position (an inheritance of the tree-climbing ability of our ancestors). From an anatomical standpoint, supination from a vertical hand is the equivalent of pronation from a horizontal hand. That is to say, a horizontal position of the hand, the extreme position

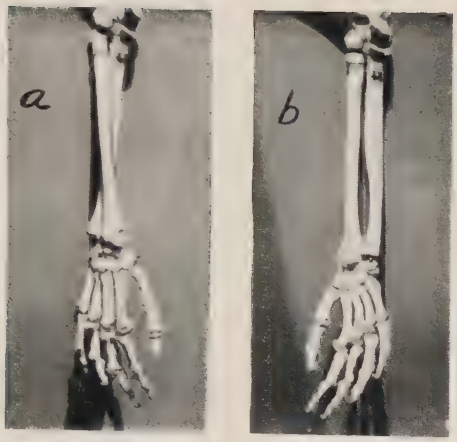


Fig. 7. The Fore-arm, showing positions of radius and ulna in pronation (*a*) and supination (*b*).

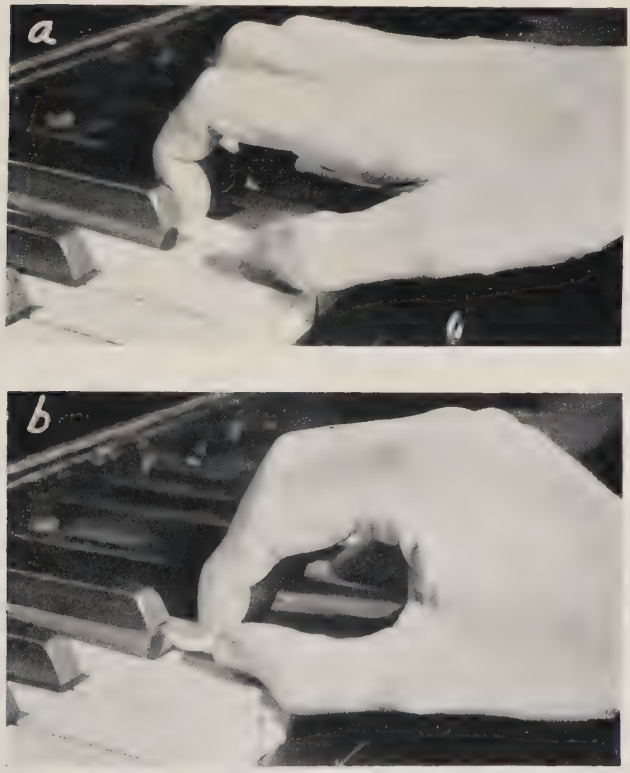


Fig. 16. Hand positions, showing differences in joint-curvature. (See p. 32.)

in supination (palm up), is the anatomical equivalent of a vertical position of the hand, the extreme position in pronation (fifth finger up, thumb down). A piano keyboard, in order to keep this equivalency would have to be built vertically, and a horizontal keyboard, therefore, makes very unequal demands upon the player in regard to ease and range of fore-arm pronation and supination. This difference, and also the direction of the axis of rotation, as we shall see, affects the piano tremolo in a very decisive way, making the pivoting on the fifth finger much easier and freer than that on the thumb.

The Wrist-Joint.—The wrist is an example of a condyloid-joint, a double hinge-joint having movement about two axes, one transverse and the other front-back (antero-posterior). The former permits movement in a plane at right angles to the transverse plane of the fore-arm (bending the hand backward), and the latter limited movement in the plane of the fore-arm. The wrist itself has no movement of rotation, this being the function of the radio-ulnar joint. Flexion and extension at the wrist (illustrated by the normal hand-staccato of the pianist) may occur through an arc of 150° or more, with marked individual variation; whereas, abduction and adduction of the hand, a sidewise bending at the wrist (used in arpeggiated chord-figures, polyphonic, and double-note passages) through 60° or 70°. This lateral movement is greater on the outer side (toward the fifth finger) than on the inner side (toward the thumb); this difference being caused, among other things, by the shorter ending of the ulna, the smaller of the two fore-arm bones, when compared to the radius, and by the position of the ligaments. A combination of the movements mentioned, results in the circular movement of circumduction, the range of which is determined by the length of the extended hand. Wide individual differences, which have a distinct bearing on piano technique, occur in the movements at the wrist joint. They are treated in a later chapter.

Hand-Joints.—The thumb has three joints, not only two; of which the first, the articulation with one of the bones of the middle hand (trapezium or greater multangular, so called from its size and shape) is the most important. This joint, located close to the wrist, differs radically from the equivalent joints of the other fingers. (See the Figures in the chapter on The Hand.) About an approximately transverse axis flexion and extension take place, as in lifting and dropping the thumb in the simple thumb-stroke on the piano; around an antero-posterior axis abduction and adduction occur, illustrated by the passing-under of the thumb in the scale and the

arpeggio. Movements combining these axes result in considerable circular movement (circumduction), and, finally, a slight rotation around the longitudinal axis of the thumb is also possible. It is this first joint, technically called carpo-metacarpal joint, that is chiefly involved in the thumb movements of piano technique. The joint is near the wrist and its articulation may be seen by touching the base of the little finger with the tip of the thumb of the same hand.

The chief biological function of the thumb movement, a function which piano pedagogy cannot disregard, is that of opposition to the other fingers. This constitutes the "grasping reflex", the fundamentality of which is shown by its early appearance in the infant. By means of it an infant only a few weeks old can support its entire body while hanging by one hand. Pianistically this coördination, in its entirety, is of little value, but a considerable part of the difficulties of learning the proper keyboard movements of the thumb is accounted for by the persistence of this deep-rooted reflex.

The second thumb-joint (metacarpo-phalangeal) is a pure hinge-joint, a uniaxial joint acting about a transverse axis, with flexion and the reciprocal extension possible through 50° or 55°. Other movements at this joint are impossible in the normal hand. But the pathological condition popularly known as "double-jointedness" is frequently seen in this joint, as a result of which hyperextension, a bending-back of the thumb through a considerable angle, is possible.

The third thumb-joint (interphalangeal or nail-joint) is a pure hinge-joint acting about a transverse axis and permitting volar flexion and the corresponding extension through 90°. Both thumb joints assist the first in passing the thumb-tip under the hand as far as possible, as in scale or arpeggio playing.

Finger-Joints.—Each finger has three joints: hand-knuckle (metacarpo-phalangeal), mid-joint, and nail-joint (both interphalangeal). The hand-knuckles are modified ball-and-socket joints with the lower (volar) spherical articular surface wider than the upper (dorsal) articular surface. Accordingly, movement is essentially directed downward and inward, toward the palm and normally not beyond a straight angle in the opposite direction. Flexion is the active movement and extension is the passive, the releasing movement, a physiological distinction that is of great importance in teaching finger-stroke. Limited circumduction, a property of all ball-and-socket joints, is possible at the hand-knuckles. A slight lateral flexion permitting the "hollowing

of the hand " is also possible, being greatest for the fourth and fifth fingers. Flexion at the hand-knuckles normally takes place through a maximum arc of 90°, extending from a straight-angle to a right-angle.

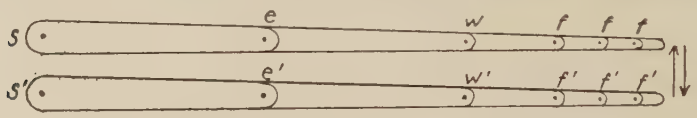
In addition to these movements, the hand-knuckles permit limited sidewise motion (abduction and adduction), movements that are referred to the middle line of the hand. They are used pianistically in playing chords in spread-position. On account of the difference between the volar and dorsal articular surfaces, however, abduction and adduction are possible only when the fingers are extended at the hand-knuckles. One cannot bend the fingers in the hand-knuckles while the fingers are widely spread, a fact that must be considered when demanding hand-arch in extended chord positions. As flexion increases at these joints, ab- and adduction become increasingly difficult, until at right-angle flexion, they are impossible. This inter-relationship illustrates the impossibility of executing widely spread chords on the piano, with an arched hand. The wider the spread the flatter must the hand be, a condition determined not so much by actual distance, as by the anatomical construction just described.

The mid-joints and the terminal, distal or nail-joints (both known as interphalangeal joints) are pure hinge-joints permitting only flexion and extension, the former joint through a maximum arc of 120° and the latter through one of 90°. This flexion normally is entirely toward the palm from a straight angle, paralleling the direction of flexion at the hand-knuckles, and acting in conjunction with this in a manner similar to the thumb-movements.

Vertical Movements

Shoulder-Girdle.—Vertical movement is possible in the shoulder by contracting the muscles of the neck and upper back. It produces, if we exclude a slight forward motion, what is popularly termed " shrugging the shoulders ". The range of this vertical motion is limited, seldom exceeding three or four inches, and thus is in accordance with the function of stability characteristic of this joint. On account of this vertical movement it is entirely possible to move the fingers through an equal vertical distance without any motion whatever in shoulder, elbow, wrist, or finger-joints. Accordingly, the hands may be brought into contact with the piano keys and withdrawn vertically from them through a short distance by muscular activity restricted entirely to the shoulder-girdle. A modification of this motion is used at times in playing fortissimo chords. In Fig. 8 and the following similar figures, s = shoulder ; e = elbow ; w = wrist ; f, f, f = finger-joints.

Shoulder-Joint.—The movement of arm-abduction and-adduction at the shoulder makes vertical movement at the elbow possible, and, through this, at the wrist and fingers. This movement, when unaccompanied by other compensatory movements, takes place in an arc of which the length of the upper arm (humerus) is the radius, and the shoulder is the centre. On account of the length



trunk relaxation

Fig. 8.

of the humerus, the range of motion is considerable. The motion may readily be observed by bending the arm at the elbow to a right angle, lifting the upper arm sidewise from the body to a level with the shoulder and then bringing it down to the side of the body. The hands may thus be brought into contact with the keys through a considerable vertical range, this time with lateral movement at the shoulder-joint.

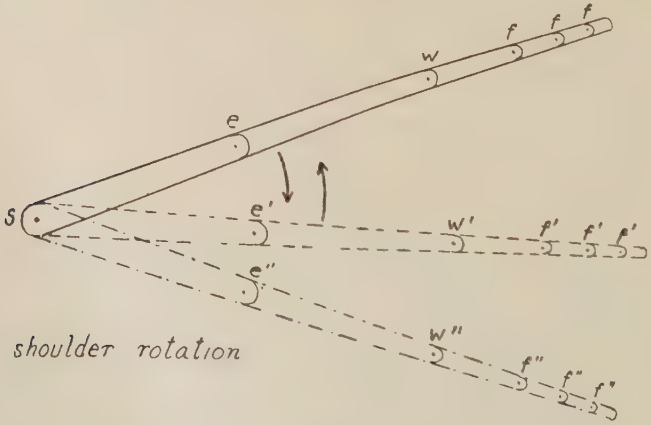


Fig. 9.

The rotation of the shoulder-joint likewise permits vertical motion of the fore-arm and hand, although in this case, the elbow must be flexed, whereas in the first illustration the flexed elbow was not necessary.

Again, if the rest of the arm be held fixed, this movement, transmitted to the hand, becomes a vertical arc, the radius of which is

the length of the fore-arm and hand, and the centre of which is the elbow. No actual movement in the elbow-joint takes place, the entire rotation resulting from a fixed arm and a rotation of the head of the humerus in the shoulder-socket. For the proper execution of this movement, as Fig. 95 shows, the upper arm must be held away from the side of the body, not close to it or in front of it. A perfect type of this motion demands a horizontal upper-arm. As the upper-arm is lowered, the vertical movement of the hand is taken care of, more and more, by movement at the elbow.

Elbow-Joint.

Since the elbow-joint is a simple hinge-joint, vertical movement at this articulation is possible when its axis is horizontal. This axis-position is present when the upper arm hangs vertically, Fig. 10. As the upper arm is lifted away from the body, this

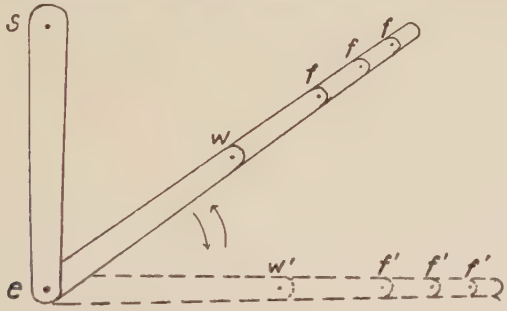


Fig. 10.

axis no longer remains horizontal and the vertical hand-movement resulting from elbow flexion and extension no longer takes place in a vertical plane, but deviates from this plane to the extent that the position of the upper arm deviates from it.

This difference is important, since it means that any vertical descent of the fore-arm with the upper-arm held away from the body—and this touch-form is constantly used in piano-playing—involves rotation of the upper-arm : a movement easily overlooked, because the upper-arm does not change its angles with regard to the adjoining parts, but merely turns on its own longitudinal axis. The degree of rotation is determined by the extent to which the arm is abducted from the vertical position. It may occur at any angle, however, because the shoulder-joint is a ball-and-socket joint which permits rotation of the humerus regardless of the angle at which this bone is held.

The older piano pedagogy, in demanding that the arm be kept at the side of the body, made particular use of the rotation of the humerus, for, by rotating the upper arm in this position, with a flexed elbow the hand is carried through a horizontal arc, from any position of which its vertical stroke is possible. The impossibility of using this touch-form in actual piano-playing is discussed under Horizontal Movements, where it is also illustrated. The vertical aspect of this touch does not introduce any characteristic that is not present in any combination of humerus-rotation and elbow-flexion.

Radio-Ulnar Joint.

The radio-ulnar joint itself is incapable of producing vertical motion in either of the bones which make up this articulation, but, as a joint of rotation, it can produce vertical movement in any part of the hand not in line with the axis of rotation. Fig. 11 illustrates this axis, looking directly along the right fore-arm from the elbow to the wrist.

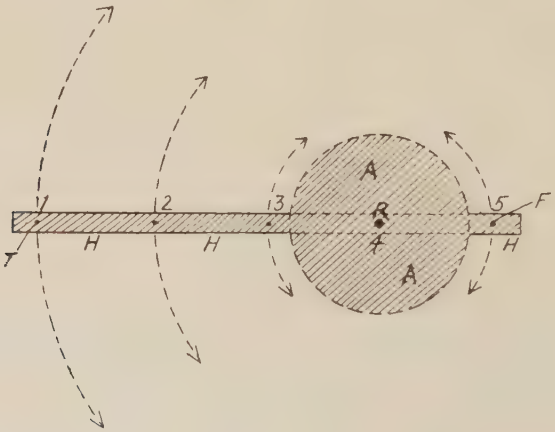


Fig. 11.

R = Axis of rotation ; H = the right hand, pronated position ; T = position of thumb ; F = position of fifth finger ; A = cross-section of fore-arm.

Any turning in the axis R will obviously cause a vertical movement at the points T and F, and the farther these points are from the axis, the greater will be the range of this vertical movement. The movement need not be restricted to the thumb and fifth finger ; for, as soon as the wrist is turned laterally, the axis no longer passes

through the fourth finger, and any finger may be shifted out of the line of the axis of rotation and hence receive vertical displacement when the fore-arm turns at the radio-ulnar joint. As a result of this motion, the fingers can receive a vertical stroke equivalent in height to the finger-stroke itself (movement in the hand-knuckle). This touch-type we shall find to be the basis of one form of the piano tremolo.

Wrist-Joint.

Vertical movement of the hand from the wrist is possible when the hand is either completely pronated or supinated. The latter position is excluded in piano-playing since the palm would be up. In the pronated position the vertical movement of the hand is a simple movement of considerable angular range, though the relative

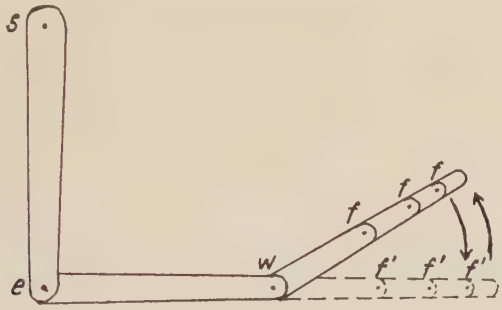


Fig. 12.

shortness of the hand compared to the length of the arm makes the absolute range small. As the fore-arm leaves the fully pronated position and approaches supination, the vertical movement of the hand is no longer entirely confined to wrist-flexion and extension, but gradually brings into play wrist-abduction and adduction. These motions are rather limited, especially on the thumb side of the hand. On the fifth-finger side abduction is sufficiently free to permit the hand to be abducted, through a small range, regardless of the angle of pronation. Fig. 12 shows vertical hand movement as used in a wrist staccato.

Finger-Joints.

If we exclude from consideration the limited ab- and adduction of the fingers in the hand-knuckles, the vertical motion of the fingers is possible only in the pronated position of the fore-arm.

Any one of the finger-joints is capable of vertical movement from this position, but in piano-playing the most work is done at the hand-knuckles (metacarpo-phalangeal joints), a fact that the excessive curve of the finger-joints sometimes obscures. With the hand in a horizontal position, these joints are pre-eminently fitted for vertical movements of the fingers. As soon as the hand deviates from the horizontal, for example when it slants toward the fifth finger, the finger-stroke can no longer be vertical. The vertical stroke is advisable, pianistically, because the piano-keys move in a vertical plane. Any slanting stroke, since it involves a change in the direction of the force and that of the body acted upon, means so much wasted work. (See Mechanical Principles, 2, 7.) The fact that in piano-playing slanting strokes are usual in all

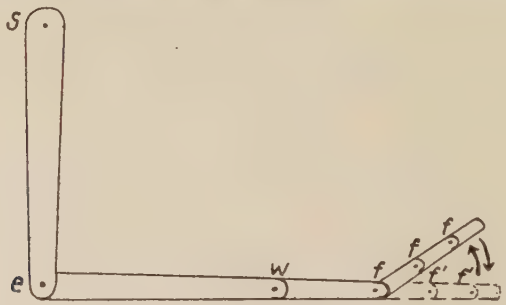


Fig. 13.

eaps does not change this fact. But when a vertical stroke is possible, it is physiological economy to use it.

The thumb-stroke differs from the stroke of the other fingers. Flexion of the thumb is basically at right-angles to that of the fingers. This is shown in the grasping-reflex, in which, as the fingers close, the thumb closes toward the fingers. If the fingers move vertically the thumb moves horizontally. In order to keep the hand in the horizontal playing-position and yet move the thumb vertically, abduction at the last thumb-joint (metacarpo-phalangeal) and not flexion, is necessary. Moreover, this abduction is accompanied by a small amount of rotation, so that the thumb-stroke is, in reality, never a straight vertical line, but always somewhat of a vertical arc. This arc is too small to make any actual difference in the tonal results of playing. The physiological difference, however, between

thumb-stroke and finger-stroke is decided; one is a movement of abduction, the other a movement of flexion.

Movement-Combinations.

The preceding study of the movement of each joint has shown that the movement which finally brings the finger-tips into contact with the piano-keys, that is to say, vertical movement at the finger-tips, can be produced, within certain limits, by any joint of the entire upper limb: the shoulder-girdle, shoulder, elbow, radio-ulnar joint, wrist-joint, or hand-knuckles. It has also shown that as movement at a joint takes place, the maximum efficiency of this and allied movements is possible with the arm in a certain position, but that the same end-movement, produced in the same way, is not possible with the arm in another position. Illustrations of this shift of function have already been given with most joints, a conspicuous example being the gradual addition of humerus rotation to elbow-flexion as the arm is lifted sidewise from the body. (See especially Fig. 95.) Given these facts, it follows that *any keyboard movement of considerable range involves a constantly changing coördination of movement among the various joints concerned.* It is never made in precisely the same way for any two positions of the arm. What to the eye is a simple continuous vertical movement, may be finished by a muscular action radically different from that by which the movement was begun. I purposely restrict the definition here to vertical movements; it holds, however, equally well for all movements, and its importance, I hope, will be realized in the detailed analysis of pianistic touch-forms.

Horizontal Movements

Shoulder-Girdle.

Horizontal movement by the shoulder-girdle is produced by bringing the shoulder-blade forward or backward, movements giving the stooped and the military positions. It may readily be observed by rotating the arm as far as possible while it hangs at the side of the body. This horizontal motion is not a straight line because, as the shoulder is brought forward it is also brought somewhat inward, describing an arc. The actual extent of the horizontal movement is not great because stability, not mobility, is the function of the shoulder-girdle; but since it acts at the centre of whole-arm movements, it may produce a movement of greater extent at the hand-end of the arm.

Shoulder-Joint.

By raising the arm to a level with the shoulder, horizontal movement at the shoulder-joint is possible through somewhat more

than ninety degrees. This range is considerably increased if the horizontal movement of the shoulder-girdle described in the

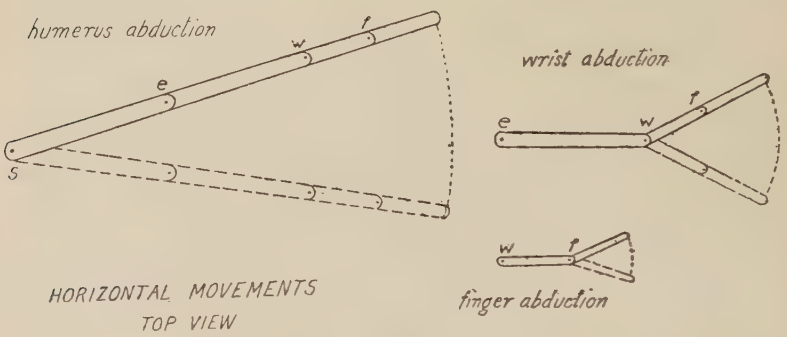


Fig. 14.

preceding paragraph be added. The ball-and-socket joint formation makes it possible to execute also a horizontal movement from the shoulder with the arm in any position except the completely vertical. The further the arm is abducted, the greater will be the range of this motion when projected to the elbow, wrist, or hand. With horizontally extended arm, the hand will describe a semi-circle the radius of which is the length of the entire arm, and, if we assume this to be two feet, the hand will describe a horizontal arc of more than six feet. As the arm is lowered from the horizontal position, or as any of its parts, fore-arm or hand, is not kept in line with the line of rotation, this distance decreases until at the completely vertical position it is zero, so long as movement in other joints does not act compensatorily. Horizontal movement of the fore-arm and hand may be produced by rotation of the humerus in the shoulder-socket. Just as, with the humerus held horizontally and the elbow flexed, rotation of the upper arm produces a vertical movement of the fore-arm and hand, so with the humerus held vertically, and the elbow flexed, rotation of the upper arm will produce horizontal movement of the fore-arm and hand, Fig. 15.

A = side view; B = top view; S = shoulder; E = elbow; H, H^1 H^2 = various positions of the hand.

Forward and backward movement at the shoulder can likewise produce horizontal motion of the fore-arm and hand in this position. If the humerus stands at any angle and the arm be drawn back so that the elbow describes an arc as it passes the body, this arc may be made horizontally, since the humerus will be describing a cone of movement of which the shoulder socket is the apex and the

elbow describes the circumference of the base. (Fig. 20.) All such movements in a single plane when initiated from a centre, such as the shoulder socket, are necessarily curved movements. Movement in a horizontal straight line is possible only when some other joint makes a compensatory movement, as the humerus swings through its arc. These combinations are analysed later.

Elbow-Joint.

Casual observation of elbow movement seems to indicate that horizontal movement of the fore-arm can be produced by elbow-flexion and extension, that is to say, by bending the elbow regardless of the position of the upper arm. This is not true. Horizontal movement from the elbow demands a horizontal upper arm. Since the elbow is a simple hinge-joint, it can operate in one plane only, and only when its axis is vertical can it describe a horizontal move-

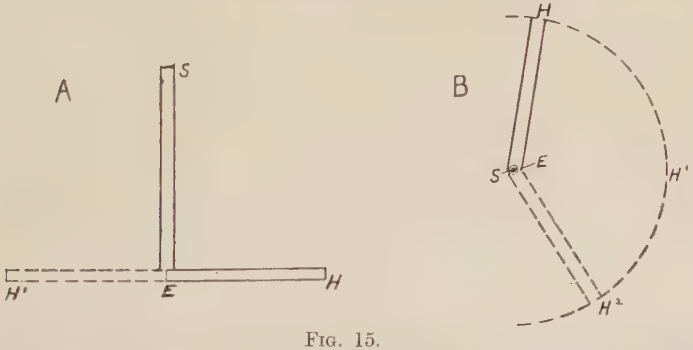


Fig. 15.

ment. As soon as the upper arm leaves its horizontal position, any horizontal movement of the fore-arm is accompanied by a rotation of the upper-arm, the extent of the latter varying directly with the amount of deviation from the horizontal. This rotation can readily be observed if the movement be watched on the naked arm. Observation of an articulating skeleton is, of course, much more convincing. Here we meet again with an instance in which movement apparently restricted to the fore-arm is in reality made possible only by rotation of the upper-arm. And as we proceed, we shall find that shoulder-articulations play a far more important part in piano-playing than that which is generally accorded them.

Radio-Ulnar Joint.

Although this articulation establishes and maintains the horizontal position of the hand, it cannot itself produce horizontal movement. Its sole movement is the rolling of the ulna over the radius, and although the movement alone is not horizontal,

it is helpful in combination with movements at other joints, making horizontal hand-movement possible, with retained horizontal hand-position, regardless of the angles of movement of the upper-arm.

Wrist-Joint.

Two types of horizontal movement are possible: flexion and extension with the hand in a vertical plane (normal supination or pronation of the fore-arm); abduction and adduction with the hand in a horizontal plane (pronated position of the fore-arm). The first type of movement is pianistically useless since it restricts the playing to the side of the fifth finger. The second type is very useful, especially in passages of legato thirds or sixths, and other polyphonic work. In any case the range of ab- and adduction is rather small, but since the width of a single piano-key (about nine-tenths of an inch) is often all the distance needed to make possible the playing of a passage, this range is, at times, sufficient. The abduction and adduction at the wrist are possible only with the hand in line with the fore-arm. If the hand be flexed at the wrist either toward the volar or the dorsal side, horizontal hand-movement is made differently, and is the result, not of wrist abduction and adduction, but of fore-arm supination and pronation. That is to say, the motion then involves the radio-ulnar joint. In piano-playing, if the elbow is on a level with the keyboard, horizontal motion of the hand may be initiated by wrist abduction and adduction. If the elbow is above the level of the keyboard, fore-arm rotation must be used in order to move the hand horizontally from the wrist. This is an instance of movement assisted by the radio-ulnar joint, another example in which a change in the position of parts of the arm not actually making the movement, necessitates a radical change in the mechanics of the movement without in the least interfering with the end-movement itself. Moreover, since the change in the position of the fore-arm from horizontal to non-horizontal may be very gradual, so the shift of mechanical operation may be very gradual. This shift of activity within a continuous movement will be referred to frequently in the discussion of muscular action in general and in that of pianistic touch-forms in particular.

Finger-Joints.

With the hand in the horizontal playing-position, the only horizontal movement of the fingers possible is the limited abduction and adduction at the hand-knuckles. Pianistically even this limited spreading of the fingers is of great importance. In the

analysis of movement at the various joints the fact was already mentioned that this spreading is widest and easiest with fully extended fingers and that it is entirely impossible with fully curved fingers (90° flexion at the hand-knuckles).

The disadvantage of the thumb-position at the key-board mentioned under vertical movements, is now replaced by a particular advantage for horizontal movements. The horizontal movement of the thumb (as in passing it under the hand in scales and arpeggios), is a natural flexion of this member, accompanied by a slight amount of rotation. The range of the movement, considering the relative shortness of the thumb, is rather great ; in any event it exceeds the lateral movement of any of the other fingers.

Horizontal Hand-Movements.

Horizontal movements of the hand, therefore, are possible from any joint of the whole arm. In this multiplicity of origins, horizontal movements are entirely like vertical movements. In both cases the same end-movement may be made in a number of ways. And, as in vertical movements, we find in horizontal movements a constant shift of reaction for each continuous movement. As the movement itself changes the spatial and mechanical relationship among the parts of the arm, so new reactions are needed to meet these changes. The transition is never made abruptly, but very gradually, so long as no external force suddenly inhibits or reinforces the movement.

Multi-planar Movements

In selecting for detailed treatment vertical and horizontal movements, I have perhaps conveyed a wrong impression of the importance and of the isolation of movement in these two planes. The selection was made solely to permit concise and clear exposition, not on account of fundamental differences between the vertical and horizontal planes, and the slanting and the multi-planar or curved movements. The conclusions reached apply absolutely in principle to movement in any one other plane. This leaves the multi-planar movements to be considered.

A very brief reflection will show that in piano-playing very few movements are made in any single plane or direction. Horizontal movements are usually combined with vertical movements. Nor is the change abrupt. Instead, practically all extended movements involve motion in many planes (multi-planar movements), and most frequently in the minute changes of direction resulting in curves. These forms complicate the mechanical reactions enormously, without, however, invalidating any of the principles

outlined for the straight-line movements. In order to save needless repetition, I shall defer their analysis until the discussion of the various pianistic touch-forms.

At this point it is necessary to mention that multi-planar movements are compounds of movement in single planes, and that curved movements are angular movements in an infinite number of planes. The principle is the same as that which considers the circle as made up of an infinite number of triangles whose bases are straight lines. The mechanical advantage of curved movements over angular movements is considerable. If the movement be angular, at each abrupt change of direction a sudden mechanical readjustment becomes necessary, the effect of which the muscles cannot readily foretell or forestall. All smooth, steady movements in the whole field of mechanics, that involve more than one direction, are movements in curves. The principles of all machines, from the mechanism of a watch to that of a turbine, are based upon rotation. Physiological mechanics are no exception to this rule. It is impossible to make a steady movement in more than one plane any other way than in a curve. This point cannot be too strongly emphasized. It is in partial, though not complete conflict with the "fixed position" school of piano pedagogy. As the deductions made for vertical and horizontal movements have shown, the entire purpose of the mechanics of the arm is to shift the centre of the work in a manner permitting the movement to go on unbrokenly. Such a shift cannot take place abruptly at one point or another. And, as a matter of fact, the various detailed cases considered have shown that it does not so take place. Nor do players play in angular movements; they use curvilinear motions almost entirely. This may be seen in the photographs in later chapters.

Keyboard Application

The various articulations of the trunk, shoulder, arm, hand, and fingers fit this compound appendage of the human body preëminently to finely controlled movements. A piano technique, since it operates entirely by means of the physiological mechanism, can be effective only to the extent to which it takes the structure and function of the various parts of the organism into consideration. Several pedagogic principles, accordingly, find their explanation in the anatomy and physiology of the joints.

In the first place, the ranges and direction of motion for the various joints furnish a concrete anatomical basis for the selection of various skeletal arm- and hand-positions in piano-playing, as more desirable than others.

Movement around a joint, since it is constantly determined, in part at least, by expansion and compression, extension and contraction of physiological tissues, cannot occur with equal ease, or against equal resistance, throughout the range of motion of the joint. It is easiest and smoothest near the middle of the range, increasing in difficulty and awkwardness as it approaches either extreme of the range. The physiological reason for this, in extreme movements, is the approach to the limit of extensibility of the tissues immediately surrounding the joint and that of the controlling muscles. Ease of motion, as we shall see, means maximum accuracy of kinesthetic judgment and minimum fatigue. Both of these are prime essentials in piano-playing. Accordingly a finger, hand, and arm position permitting the joints to operate near the middle of their range, is, other things equal, the most desirable for piano-playing. This can be determined for each joint.

The upper arm (humerus) since it abducts between a vertical and a horizontal position theoretically has its easiest range at 45°. But abduction acts against gravity, so that the ease of range is skewed toward the vertical.

The elbow flexes from a straight angle to 30° or 40°. But right-angle flexion already brings the flesh on the volar surface of the lower and the upper arm into contact, and flexion beyond this point has this additional resistance to overcome. The elbow bent through an arc somewhat less than a right angle, therefore, gives approximately the easiest position for this joint.

The lateral movements at the wrist are rather restricted in range, so that any ease of motion would be through a proportionately small range. Since turning the hand extends slightly further toward the fifth-finger side, than toward the thumb side, the position of easiest movement would be slightly outward from the straight position of the hand, and accounts for the readiness with which the hands of untrained pupils assume the "wrist-in" position at the keyboard. The lateral wrist movement is important on account of its effect upon the axis of rotation of the fore-arm. By turning the hand outward slightly at the wrist, the fore-arm axis, which in the unturned hand, passes through the fourth finger, may be shifted to the third finger, thus dividing the hand more symmetrically. A further lateral turn at the wrist will shift the axis still further toward the thumb side of the hand. The practical benefit of this shifting will be seen when we discuss the tremolo touch and polyphonic playing.

Flexion and extension at the wrist embrace an extreme arc of 180°. Normally this falls equally on the two sides of the position

when the hand axis is a prolongation of the fore-arm axis, which, accordingly, becomes the easiest position. So far as the position of the wrist alone is concerned, the old instruction books, now considered obsolete, were absolutely right in demanding a position in which the back of the hand and the arm form a straight line. The awkwardness of this hand-position is the result of the positions it necessitated for joints other than the wrist-joint.

The easiest range of action for the three finger-joints may be similarly determined. When this is done and allowance made for the resistance of the fleshy volar surface of the fingers in extreme flexion, the mid-points will be near 40° for the metacarpophalangeal joint (hand-knuckle), 45° for the middle joint, and 30° for the nail-joint.

A combination of these joint-angles gives us the easiest position of the hand as a whole. The final position of the finger-tip would be the result of a summation of all the angles, beginning at the wrist. This gives an angle over 100°, which measured from the horizontal wrist position would force the finger-tip beyond the perpendicular position and bring the finger-nail in contact with the surface of the piano-key.

Apart from the inflammation which usually follows constant striking of the nail against the key, the impact noise, also, is musically undesirable. Consequently the fleshy part of the finger-tip is best fitted for striking the key. In order to permit this, the angle of curvature of the finger must be reduced to about 80°. This may be done in either of two ways: by decreasing the angle at one or more joints, or by dividing the difference among the four joints. The former produces the hand-position in use a generation or so ago. Here the excess curve was entirely taken up by the hand-knuckles so that these joints are fully extended as in Fig. 16*a*. Or if the nail-joints be changed, the middle-finger joints are excessively curved, as in Fig. 168, a position occasionally found in pupils whose curvature of the nail-joints is defective. Either position necessitates movement near the extreme of range in some joint and is physiologically undesirable for normal position. By dividing the excess curvature among the various joints, the hand-position recommended by modern piano pedagogy is produced. Here the wrist is slightly depressed, the back of the hand ascends toward the hand-knuckle, and each finger-joint is extended slightly from the position given, as shown in Plate I, Fig. 16*b*. All joints now move through an approximate mid-range, thereby permitting maximum accuracy with minimum fatigue. The choice of this hand-position in preference to others, apart from later considerations

of muscular action, is thus seen to be entirely in accord with the anatomical structure of the fingers and hand, and not the result of whim and fancy.

A combination of the foregoing positions produces what may logically be called the normal arm-wrist-hand-position. It is the basic position of reference, and is useful for purposes of orientation, although it is seldom applied intact for any length of time in actual piano-playing, which, we must remember, is movement, not position.

From the practical standpoint, an important conclusion to be drawn from the articulations of the joints is that, with a few exceptions at the extremes of range, any point in the space covered by the arm and its appendages, can be reached in various ways. Sitting in the normal position at the keyboard, for example, C^3 can be reached with the upper arm in any position from complete abduction to complete adduction. Or this key can be reached with the fore-arm in any position from complete extension to 90° flexion (the latter by bending the trunk forward, bringing the shoulder more nearly over the keyboard). One can, further, play the key from any position whatever of the wrist, lateral or vertical, and with any finger in any position. Finally, by bringing the left shoulder forward and extending the arm, the same key can be reached with any finger of the left hand. Practically any other key can be reached in as many and more ways. Four pedagogical principles follow, which should constantly be recalled when position is being stressed by the teacher at the expense of movement:

(1) Any key on the piano may be reached effectively in a multitude of ways.

(2) The position in which any key is played is determined by the position and manner of playing the preceding and succeeding keys.

(3) The best manner of making a movement to a certain point on the keyboard varies with the individual, and, among other things, is determined by skeletal structure.

(4) The physiologically best movement is the one permitting motion near the middle of range of the joints involved.

Another conclusion to be drawn from the skeletal structure of the shoulder region and arm is that any extended movement of hand or finger involves movements in all the other joints. Or, if we except the few extreme instances of minimal and restricted movement, we may say: every actual movement made in piano-playing involves simultaneous movements in various joints, the degrees of participation varying as the movement continues.

(See Geometrics of Movement.) This is necessary in any structure organized as the arm is organized. The vertical finger-stroke, while apparently merely a movement in the hand-knuckle, is accompanied by a slight extension in the two interphalangeal joints, otherwise the top of the nail, and not the fleshy part of the finger tip would strike the piano-key. In the putting under of the thumb in scale and arpeggio work, flexion in the first joint is necessarily accompanied by extension in the other two thumb-joints, so that the nail-joint remains parallel to the key, avoiding the striking of two adjacent keys. Even in hand-staccato, which appears to the eye, perhaps, as the most isolated technical movement, a slight opposite motion of the fore-arm may be detected, not to mention motion in the shoulder if the passage be extended. The so-called simple "arm-drop", a free falling of the arm, and the exercise given to beginners to insure relaxation, if accompanied by key-contact, involves some movement in practically all arm and finger-joints and is not restricted, by any means, to movement in the shoulder-joint. In other words, whenever any part of the body changes its position with regard to an adjacent part of the body, movement has taken place in the joint between the parts, and often in joints closer to the trunk.

It is true that from a skeletal standpoint alone movement may be restricted to a single joint; but in actual piano-playing such complete restriction, although often apparently taught, is not applied. The reason for this is evident from the analysis of mechanical action and reaction, and from the action of the muscles described in a later chapter. Nor is the range of movement for each of the joints clearly differentiated from that of each other joint. Skeletal movement is not marked by a position on one side of which all movement in one joint takes place, and on the other side, all movement in another joint. Instead there are regions of movement in which the various joint-movements overlap. A movement starting essentially with an articulation in a single joint, will, if extended, gradually bring into play other joints, and the exact point at which this spread or transfer takes place cannot be clearly determined, since it in no way interferes with the continuity or smoothness of the movement. As a matter of fact the smoothness depends upon just such a gradual spreading or transfer of activity. This is generally known as the coördination of movement, a subject that will be treated in detail in a later chapter. Its mention at this point is advisable to explain the fact that what is considered by the layman, and by many piano teachers, movement in merely one joint, is often a very complex movement involving articulation

in several joints. For the piano teacher localization of a defect in motor adjustment in the proper joint is of fundamental importance, because, only when the source of trouble is located can remedial measures be applied intelligently.

Shoulder-Girdle.

Vertical movements of the arm are the result of movements in the shoulder-girdle and shoulder-joint. Withdrawing of the arm-weight from the piano-keys is due to a contraction of the weight from the entire shoulder-girdle, and not to a "stiffness" in the shoulder-joint. Even the neck may be involved. This condition is typified in the expression "shrugging the shoulders", and is caused not by movement in the shoulder itself but in the shoulder-girdle.

All movements demanding the passages of the arm in front of the body, illustrated in the passages which demand a crossing of the hands, or a playing of the right hand in the bass and the left hand in the treble region, and, of course, the reverse movements, are primarily movements of the shoulder-girdle, demanding a "stooped" shoulder position. They are often erroneously assigned to the shoulder-joint entirely.

Shoulder-Movement.

The great mobility of the shoulder-joint, (not of the shoulder-girdle) makes it serviceable in many diverse movements. One of its important functions pianistically, is to permit the vertical movement of the fore-arm used in playing strong, detached chords. These are not played entirely "from the elbow", but in addition by a rotation of the humerus in its socket at the shoulder. The elbow being at the same time bent, is forced to transmit this rotation into a vertical motion of the fore-arm, hand, and fingers, in all positions in which the upper arm is not vertical. (See Fig. 95.)

The forward and backward motion takes care of the placing of the hands forward on the keys, and their reverse removal, as well as the shifting from the white to the black keys. It also aids the shoulder girdle in permitting extended lateral movements into the extreme ranges of the keyboard.

Abduction and adduction likewise contribute to lateral movements of less extent. The playing of a scale upward from middle C through several octaves is accompanied by abduction in the right shoulder-joint. In fact any lateral movement along the keyboard, extending beyond the five-finger limit, is made with some ad- or abduction at the shoulder. This includes scales, arpeggios, hand-skips, octave passages on non-repeated keys, and all mixed figures demanding a sidewise shift of the hand.

Since the combination of these movements cover all three dimensions used in piano-playing, the vertical, the lateral-horizontal, and the forward-backward horizontal, the importance of the shoulder-joint movements in piano-playing is manifest. This importance is often overlooked since the amount of movement is minimal at this point (necessarily so, since it is the base of movement), whereas the maximum amount of movement is in the hand or fore-arm, where it can be much more readily seen, and to which the source of movement is, therefore, falsely attributed.

Elbow-Movement.

In piano technique elbow flexion and extension are most pronounced in lateral shifts approximately within an octave. Beyond this range shoulder abduction, as we have seen, aids the shift. The vertical movements of the fore-arm, with abducted humerus, have their source partly in the shoulder.

Radio-Ulnar Movement.

This joint, located in the region of the elbow, is the source of all keyboard movements involving the rotation of the fore-arm, as in the tremolo, broken-chords, melodic accentuation, and, sometimes, phrase-release. The range of rotation causes an unequal distribution of arcs for the thumb and the fifth fingers. Accordingly, it is much easier to hold the fifth finger on a key and to lift the thumb into a vertical plane above it, than to hold the thumb and lift the fifth finger into such a position. When the teacher insists upon this extreme latter motion, the last forty-five degrees of it is usually made, or at least accompanied, by abduction at the shoulder. This points to the fact that, in teaching the tremolo, a moderate amount of rotation, or at least less rotation over the thumb as pivot than the fifth finger, is necessary, if the object be to restrict the movement to the radio-ulnar joint. Broken chords, particularly where the lower notes of the chords do not require a holding of the keys, are most effectively done by a rotation of the fore-arm. I refer to such passages as in Chopin's Etude in E♭, Op. 10, No. 11.

Wrist-Movement.

Contrary to popular belief, the wrist has no movement of rotation at the wrist, but only because the wrist is a part of the entire rotating member. The source of this movement of rotation has been discussed in the preceding paragraph.

The most widely used wrist-motion is flexion and extension, having its chief key-board application in the hand-staccato, or wrist-staccato. This is the touch used in normal octave passages,

staccato chords, and staccato in general. It is a touch-form of considerable range since it is a part excursion of a joint having movement through 150° or more. Examples of its use abound in piano literature: any Staccato Etude, such as Rubinstein's C major; the staccato chord variation of Schumann's Symphonic Etudes; the staccato variation of Mendelssohn's Variations Serieuses.

The lateral movement of the wrist is skeletally much more restricted. It is useful in extended broken chord work, characteristic of the works of Schumann, Chopin, and Brahms. It likewise aids in the passing under of the thumb and the passing over of the hand in scales, and more markedly so, in arpeggio work. The attempt to restrict this technique entirely to thumb-movement cannot be effectively carried out, since it robs the total movement of the freedom necessary for a plastic performance of the arpeggio. This point will again be touched upon under Individual Differences and under Touch Forms.

Thumb-Movement,

Thumb-action plays a very important part in piano-technique, because it is the normal way of extending a legato beyond the five-finger limit. The difficulty in developing a proper thumb-action is found in the double-action necessary. The normal thumb movement is flexion and extension at the carpo-metacarpal joint. This movement readily permits the passing of the thumb under the hand. But in order to depress the piano-key, a vertical movement is necessary, which, with the thumb in a flexed position (under the palm of the hand, as in scale-playing), is not a natural movement. It is this double movement, in planes at right angles to one another, that makes the difficulty. The pianistically opposite movement, that of passing-over the hand, is, in reality, not an opposite movement. It is not a hand-movement, but an elbow movement, accompanied by humerus rotation and by passive flexion at the carpo-metacarpal joint of the thumb, and is more readily made because it does not demand a vertical thumb-stroke. For this reason pupils as a rule find descending scales in the right hand, or ascending scales in the left hand, easier than those in the reverse directions. In the former case the hand is passed over by movement in the elbow-joint and the key is played by a movement in a finger-joint (metacarpo-phalangeal), whereas, in the latter case, both lateral and vertical movements are made primarily by the same thumb-joint. The same observations, on a more extended scale, apply to arpeggio technique.

The two remaining thumb-joints aid in keeping the tip of the thumb parallel to the piano-key. They are flexed most when the thumb is in its normal position next to the second finger. As the thumb passes under the hand, flexion increases at the carpo-metacarpal joint, while it decreases in the two remaining joints, the middle and the nail-joint. Accordingly, any lateral movement of the thumb when applied to the piano keyboard, involves movement in all three thumb-joints.

Finger-Movement.

If we allow for the difference in the direction of the movement, finger-stroke is the equivalent of thumb-flexion, the former acting vertically and the latter horizontally. Several types of finger-stroke are possible. By restricting the movement to the hand-knuckle (metacarpo-phalangeal) the finger-tip may be brought into contact with the piano-key by an arc movement, Fig. 104, *a*, *b*, *c*, either with flexed or extended finger; by simultaneous flexion in the three finger-joints the key may be stroked, Fig. 104*c* (the stroke staccato of the early instruction books), and, finally, flexion at the hand-knuckle may be accompanied by extension in the two other finger-joints, producing the vertical finger-stroke of the more recent pedagogy, Fig. 104*b*. Finger release may be a continuation of the key attack, resulting in an elliptical movement of the finger-tip, or it may reverse the movement exactly, the finger-tip returning over the same path described in its descent. We are here not concerned with the various advantages and disadvantages of these action-types, but merely with the possibilities for movement at these joints. This we have seen, is possible at any vertical angle. Finger flexion and extension is by far the most important pure finger-action used in piano-playing. And, as in the case of the thumb, it is seldom restricted to one joint alone, but involves to a great or small extent, movement in each of the finger-joints. The fifth finger, when this is lifted in the extended position, is a partial exception to this rule.

If action at the metacarpo-phalangeal joints were entirely restricted to flexion and extension, the playing of chords extending beyond the five-finger limit would be impossible. Such a position demands a spreading of the fingers, which can occur only by abduction at the hand-knuckles. The construction of these joints is such, however, that this abduction is dependent upon the degree of flexion. It is greatest when the fingers are entirely extended, it is practically zero when the fingers are flexed to 90°. Consequently, greatest spread of fingers demands an entirely flat hand. By insisting upon an arched hand we markedly restrict the spread

of the fingers. Nor is this the result of greater distance demanded by the arched position, it is the result of the inability to abduct the fingers in a flexed position. Flat fingers, therefore, in extended chord work are not only natural, but often the only means of getting the necessary finger spread. To demand curved fingers under such conditions is pedagogically unsound, since the vertical finger-stroke can readily take place entirely from the hand-knuckles. (Fig. 105*a*.)

The preceding analysis of joint-movements furnishes the skeletal basis for piano-playing. It brings to light:

(1) That practically all movements of piano technique are movements in more than one joint, in spite of the attempts of many pedagogues to restrict them to a single joint.

(2) That the range of movement is ample to cover any point in the entire sphere of movement, limited by the length of the extended arm.

(3) That the main source of movement is never in the joint that is actually moving. In order for any joint to move as a whole, some other joint, situated closer to the trunk, must serve as stationary fulcrum.

Finally, the question arises: to what extent can the skeletal part of the hand or arm be modified by appropriate massage or so-called "stretch-exercises"? So far as the skeletal part itself is concerned, very little indeed. In order to modify the bone articulations themselves, a beginning would have to be made in early infancy. At this period, the temporary cartilages have not yet been replaced to any extent by permanent, harder bone, and hence are more readily subject to modification. Fortunately, the "tightly-knit" hand, often erroneously attributed by the teacher to joint-formation, is usually the result of supernormally tight ligaments, excessive flesh around the joints or even muscular limitation. Here massage helps considerably since all living tissue, as all living matter, is biologically adaptable. On the other hand, such massage should be carefully administered and should never be undertaken with the idea of forcing physiological changes in a short time by sufficiently intense applications. These are almost invariably injurious; the classical example of Schumann, with the device for isolating the fourth finger, may serve as a reminder. Variations in joint-movement are discussed in detail in the chapters on Hand Measurements and Individual Differences.

CHAPTER III

The Muscles

Opposed to the passive nature of the skeletal structure is the active nature of the muscles. These are the organs of movement, that part of the anatomical structure which makes possible, without outside force, the movements described in Chapter I. Muscles divide into two classes : skeletal (striped) and visceral (unstriped). Skeletal muscle governs the bodily movements of rotation and translation, visceral muscle governs the activity of the internal organs such as the heart, lungs, and stomach. Our problem excludes consideration of visceral muscle.

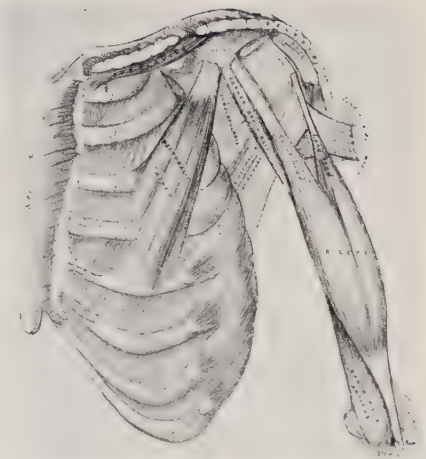
Shape of Muscles.

Each muscle is a combination of a great number of muscle fibres or muscle cells. Usually it is thickest at or near the middle of its length and tapers off at both ends into tendons attached to the bones. The fibres are grouped into bundles of various sizes and the entire muscle is enclosed in a sheath. To this muscle-form, however, there are numerous exceptions. If the muscle divides at one end into two parts it gives the biceps form ; a division into three parts gives the triceps form. Some muscles, whose function is range rather than power, are long and slender, others whose function is power, are short and thick. In some cases the tendon at one end is missing, the belly forming the actual point of attachment.

The muscle fibre of popular parlance is something essentially different from the muscle-fibre of the anatomist. Since the muscle substance itself is quite soft, it is inclosed in a connective tissue, which, besides holding the muscle substance in place, transmits the pull of the fibres to the tendon and through this to the point of attachment, thus producing movement.

Shoulder-Muscles.

The shoulder embraces a group of eight muscles, five of which are directly attached to the shoulder-girdle and the trunk. Through their combined action the shoulder-girdle may be raised (shrugged), lowered, brought forward or backward, and circumducted. The muscles moving the shoulder girdle are trunk muscles situated in the neck, chest, and back, not in the shoulder itself. The muscles in the shoulder itself move the upper-arm and not the shoulder.



A

B

C

Fig. 17. A, B, C, The Muscles of the Chest, Shoulder and Upper Arm. Modified after Gray.

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One of the largest muscles of shoulder-movement (trapezius) is situated in the upper central region of the back. Its function is to draw the shoulder-blade backwards and upwards. By a combination of opposite actions of various bundles of fibres of this muscle, the shoulder socket may be rotated, permitting the arm to be raised in a forward direction above the head. Another muscle (latissimus dorsi) is situated lower in the back and besides controlling inspiration at the lungs, also adducts and rotates the upper arm. A smaller muscle (levator scapulae) raises the shoulder-blade, whereas the two rhomboid muscles control the inner end of the shoulder-blade.

In the shoulder proper there are five muscles, of which the deltoid, which forms the fleshy outside covering of the shoulder-socket, is the largest. The main action of the deltoid muscle is to raise the arm from the side and to bring the upper arm into a horizontal position. The front portion of the muscle assists also in drawing the arm forward and the back portion in drawing it backward. This division of function is quite characteristic of muscles, and is one of the strongest arguments against the fallacy of teaching muscle-isolation in the various pianistic touches. Two smaller muscles (the supraspinatus and infraspinatus) assist the deltoid in its actions, the former in arm-abduction and the latter in drawing the arm back at the shoulder-joint. Two remaining muscles (teres minor and teres major) are rotators of the upper arm.

In any shoulder movement, therefore, more than one muscle is usually involved; two contribute to abduction (right hand ascending along the keyboard), seven, exclusive of the action of gravity, to adduction (right hand descending along the keyboard), five each to forward and to backward movement (shift from white to black keys and reverse), three to lateral rotation and four to medial rotation. Moreover, if the movement be extensive, the action of one muscle is superseded by that of another without the interposition of any break. The transition is gradual, and is often present also in movements of small range. It accords with the skeletal movements described in the preceding chapter. These, too, have shown the gradual shift of mechanical work during the course of a single movement.

Muscles of the Upper Arm.

The muscles situated in the upper arm govern the movements of the fore-arm. They fall into two classes: the anterior flexors and supinators (biceps and brachialis) bending the arm at the elbow and turning the palm of the hand up; and the posterior

extensors and pronators (triceps and subanconeus) extending the arm at the elbow and turning the palm of the hand down. The former group is situated chiefly along the inner (volar) half of the upper arm; the latter group along the back (dorsal) half of the upper arm. The specific action of each of these muscles is not always clearly defined. Thus the biceps muscle is assisted by at least two others in raising the fore-arm. In fact, although it is popularly believed that the biceps is the main if not sole flexor of the elbow (for example, when one says, while bending the arm: "feel my muscle"), it is the triceps muscle (along the back of the upper arm) that is at least partly, if not equally, responsible for flexion, while the biceps is the chief supinator of the fore-arm. This is shown by the fact that when a person demonstrates the full prowess of his biceps muscle he does so invariably with the fore-arm well supinated, that is to say, with the palm turned up. By flexing the elbow so that the back of the hand, instead of the palm, approaches the shoulder, the biceps muscle will not contract, but will do so if we turn the fore-arm while keeping the arm in the flexed position. All this proves again the essentially integrative, not disintegrative, action of muscles.

Moreover, the action of the biceps itself is complex. The muscle usually assists movements at two joints: the elbow and the radio-ulnar joint. It may assist movement at the shoulder when the fore-arm is fixed. The simplest combination, perhaps, of these actions is seen in the movement made when passing the hand to the mouth.

We have, then, the interesting physiological fact that not only are various muscles usually active in any movement, but the same muscle contributes to a great variety of movements and may act upon more than one joint. Flexion at the elbow may involve as many as seven muscles and conversely, the brachioradialis assists in both flexion and pronation, and extension and supination. Its function is to bring the hand into a mid-position from either extreme of its range. For a picture of these muscles see Fig. 17, A, B, C.

Muscles in the Fore-arm.

The muscles situated in the fore-arm regulate the movements of the hand and some of those of the fingers. They fall into four general classes: flexors and extensors of the wrist; flexors and extensors of the fingers; pronators and supinators of the fore-arm; abductors and adductors of the wrist. On account of the form of the wrist-joint, flexion and adduction are more extensive movements

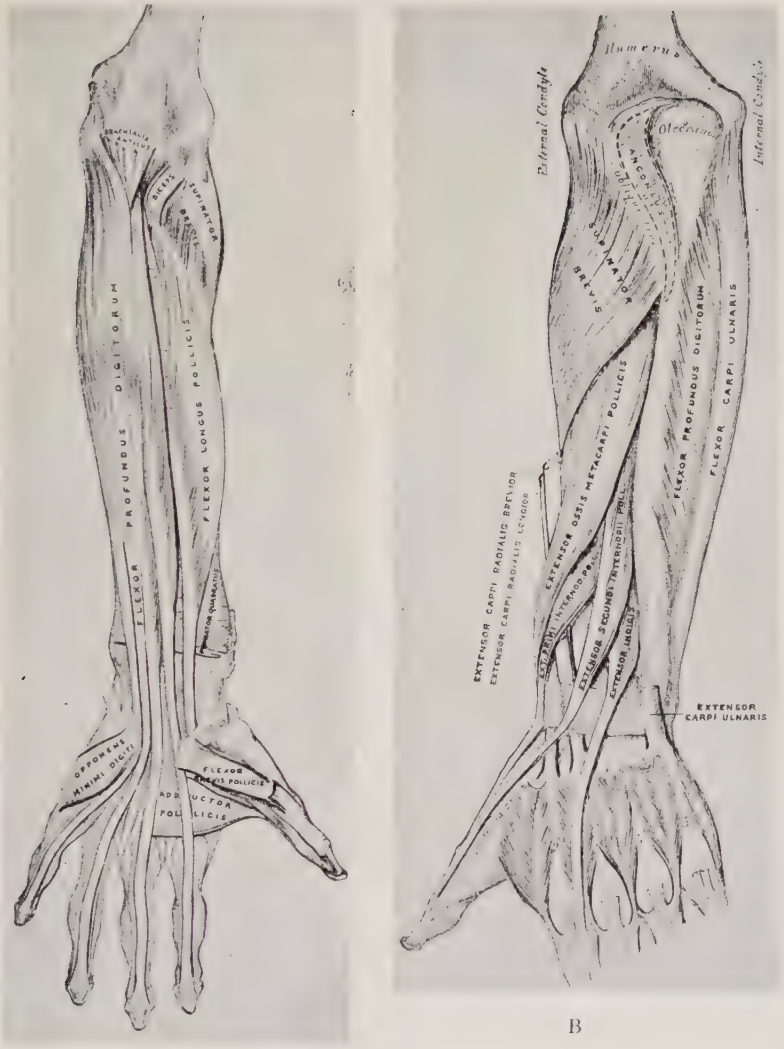

Fig. 18, A, B, The Deep Muscles of the Fore-arm: A, ventral aspect; B, dorsal aspect. Modified after Gray.

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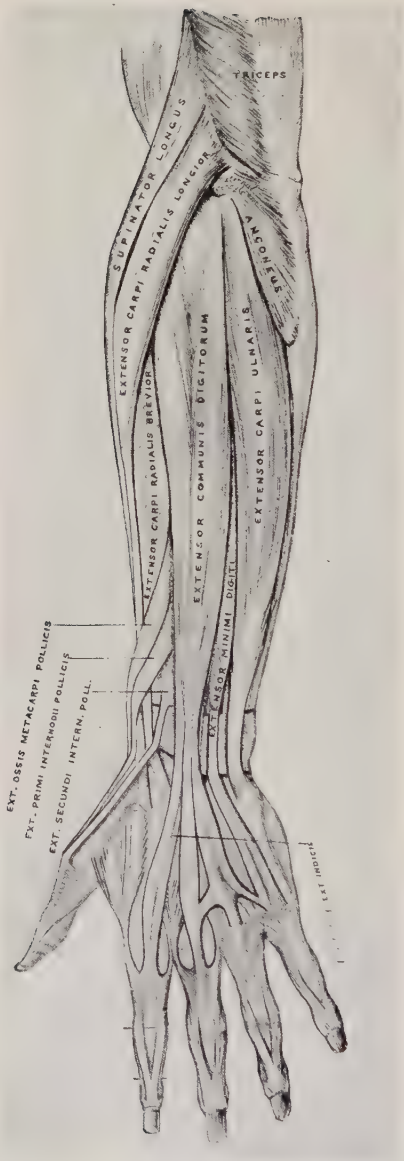

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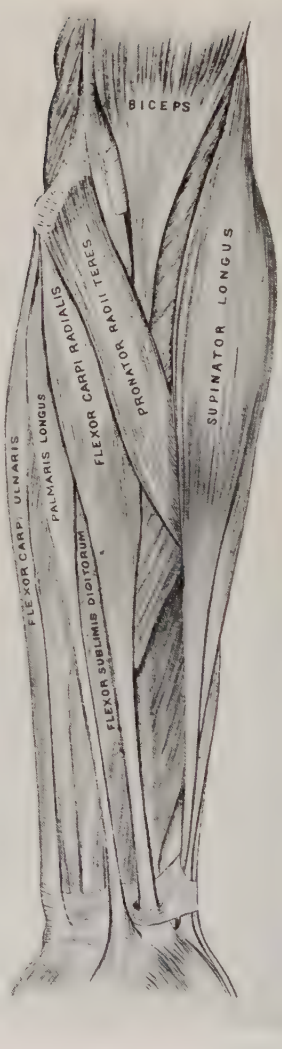

D

Fig. 18. C, D. The Superficial Muscles of the Forearm: C, dorsal aspect; D, ventral aspect. Modified after Gray.

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than extension and abduction. In any movement more than one muscle is involved. In flexion and extension of the wrist two sets of muscles may be active : the flexors and extensors of the hand (carpus) and those of thumb and fingers. If the wrist be flexed or extended with the hand in a fist-form, the movement will be less than when the fingers are extended also. This illustrates the summation of the action of the two sets of muscles. The extensors of the fingers aid the flexors to bend the hand forward. It is more noticeable here in flexion than in extension.

The wrist-joint bends more readily backward than forward, a remnant of the time when the fore-limbs were still used for locomotion, which also accounts for the fact that the hand and finger knuckles do just the opposite. The greater range of lateral wrist motion toward the fifth-finger side of the hand is the result, not so much of muscular action, as of skeletal structure, the ulnar bone being shorter than the radius. Wrist abduction and adduction, moreover, depend upon the extensor-flexor position of the wrist. When the wrist is bent back (dorsally flexed) abduction and adduction at the wrist are impossible and are replaced by supination and pronation of the fore-arm, so that with the hand out of line with the fore-arm we cannot turn the hand sidewise without rotating the fore-arm in the radio-ulnar joint. Lateral wrist motion, accordingly, is possible only with the wrist normally extended, that is to say, when the flexors and extensors of the wrist are in a state of equilibrium. All this is natural, since the object of movement is to enable a part of the body to reach a desired point and the same point may be reached by the fingers either through wrist extension plus abduction, or through wrist-flexion and fore-arm supination. Nature is not concerned particularly with the means, so long as the goal is reached.

The muscles of supination are much stronger than those of pronation, a difference utilized in the direction (to the right) in which a screw-driver is turned. Although a movement may objectively appear the exact reverse of a given movement it does not follow that the two are exact physiological opposites. One often involves greater muscular effort than the other. A conspicuous example of this is the difference between the power of supinating and that of pronating, just mentioned.

Muscles in the Hand.

The hand contains three sets of muscles : a middle set (interossei and lumbricales) ; an external set (thumb muscles) forming the fleshy part of the base of the thumb (the thenar eminence), and

an internal set (fifth-finger muscles), forming the hypothenar eminence. The middle set is concerned with the actions of the fingers, the other two sets assist in "hollowing" the hand by bringing the thumb and fifth finger closer together.

The basic movement of the parts of the hand is that of opposing the thumb to the fingers. The hand is thus divided fundamentally into two parts: thumb and fingers. This division is clearly illustrated in the "grasping" reflex of the infant already mentioned. Pianistically, in a modified form, it is found in the "passing-under-of-the-thumb" in scales and arpeggios. It is quite characteristic of the untrained adult to play bits of pieces by "bunching" the four fingers, a further illustration of the physiological fundamentality of the division into fingers and thumb.

The next finer division of the hand, separates the four fingers into two groups: the second finger as one, and the third, fourth, and fifth fingers as the second group. This division is illustrated in the extension of the second finger while the others are flexed. Hence the name "index" finger. The anatomical basis for this separation is found in the accessory tendons (vinculae) which connect the third, fourth, and fifth fingers, but leave the second finger free. The unequal freedom of the third, fourth, and fifth fingers results largely from the fact that the fifth finger action is materially helped by the muscles forming the hypothenar eminence, which re-enforce the finger flexion muscles, whereas the greater freedom of the third finger over the fourth results in part, from its freedom on the second finger side. The fourth finger, on the contrary, is attached on both sides. This is the characteristic "weakness of the fourth finger", the bane of most piano students. The tendonous interconnections between third and fourth, and between fourth and fifth fingers, account for the tendency of the untrained student to "slur" over passages involving these fingers.

Several characteristics of finger-motion deserve mention here. Since the normal finger-position, in regard to lateral motion (abduction and adduction), is parallel to the mid-line of the hand, abduction, a drawing apart or a spreading of the fingers, requires more muscular effort than adduction, a bringing-together of the fingers. A transition, therefore, from close to open position (diatonic or chromatic progressions to arpeggio), is accompanied by an increase of effort; whereas the reverse transition is accompanied by a decrease. The practical effect of this is discussed later.

The interossei are often treated as flexors of the hand-knuckles as well as of the finger-joints. This is not true, for we can flex (bend) the hand-knuckles and keep the fingers straight, as in the

Fig. 18. E. The Muscles of the Hand, palmar view. Modified after Gray.

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characteristic position of certain forms of chronic rheumatism (osteoarthritis). If the same muscles performed flexion at all of these joints we should have the paradoxical condition of the same muscle being in states of relaxation and contraction at the same time. For a similar reason the lumbricales do not assist in flexing the two finger phalanges, because we can bend or straighten the finger-joints whether the hand-knuckles be flexed or extended. Flexion at the hand-knuckle is performed by the lumbricales. Thus two sets of muscles are involved in finger-action, one governing movement at the hand-knuckles (metacarpo-phalangeal joints), the other, movements at the finger-joints (interphalangeal joints). The lumbricales are the muscles chiefly concerned in rapid movements of the fingers as used in piano-playing. (Cowper, accordingly, named them musculi fidicunales.)

The two sets of finger muscles: abductor-adductor set, and flexor-extensor set are mutually dependent, to a certain extent, in their actions. Thus abduction and adduction are seriously interfered with, in most cases they are made entirely impossible, with flexion at the hand-knuckle. This has already been pointed out in discussing movement at the joints. The greater the extension at this joint, the wider the abduction, so that a spread chord cannot be played with the fingers in a vertical position. This is not a self-evident fact, for, given a different muscular-skeletal construction at the metacarpo-phalangeal joints, the same width of stretch could be reached with the fingers in a vertical position, since the length of fingers remains the same.

If we bend the middle finger-joint (proximal or first interphalangeal joint), the nail-joint loses its power of extension and, unless bent (flexed), will hang loose: a factor contributing materially to the "breaking-in" of the nail-joints in young and inexperienced players. Since the same muscle (extensor communis) acts upon both interphalangeal joints, a separate extension of either is normally not possible. This condition does not apply to the thumb, for the extensor muscle here (longus policis) is a separate muscle, for each interphalangeal joint.

A source of constant trouble to the piano teacher is the limitation in movement of the fourth finger. This results, primarily, from the presence of ligamentous bands connecting the tendon of this finger with that of the third and that of the fifth. These bands are shown in Fig. 18 C. Their position indicates that they limit extension of the finger, not flexion. That is, they affect finger lift, not the down stroke. No amount of practice can overcome entirely this physiological limitation. What practice does is to extend the

band very slightly and to increase the force of the fourth finger stroke, thus making less lift necessary for the production of a tone of given intensity. The fourth finger never reaches the independence of the others. The following figures give the distances through which each finger, after prolonged drill in extending this range, could be lifted in a particular case. The hand was held in a normal position for playing, and as each finger was lifted, the remaining fingers remained in contact with the key surface. The distances given are the vertical distances between the finger-tip and the surface of the piano-key.

Right Hand: Second finger, 3·25″; third finger, 2·80″; fourth finger, 1·60″; fifth finger, 2·50″.

Left Hand: Second finger, 3·25″; third finger, 2·80″; fourth finger, 1·50″; fifth finger, 2·50″.

Training thus changes the absolute amount of finger lift but not its relation to that of the other fingers.

Finally the presence of two small muscles explains the greater lift for the second and the fifth fingers. Each of these digits has an additional extensor, helping to increase its range of lift. The subdivisions of the hand, illustrated in Fig. 165, showing the isolation of fifth and second fingers, are thus seen to have a muscular cause. (The two muscles in question are the *extensor indicis* and the *extensor minimi digiti*.) (See Fig. 18, A, B, C, D.)

Muscles of the Thumb.

The movements of the thumb are performed by eight muscles, four of which are situated in the fore-arm and four in the thenar eminence. Of the four muscles in the fore-arm three are extensors, one for each thumb-joint. The action, however, is not entirely isolated. One of these extensors (longus pollicis) extends the thumb-tip, but if the movement be continued it acts also upon the other thumb-joint. This extensor is attached to the bone differently from the similar tendon in the other fingers. Accordingly, the impossibility of extending the nail-joint while flexing the other joints does not hold for the thumb.

As in the case of all the muscles thus far considered, the muscles of the thumb show clearly the integrative action of the muscular system. The short extensor of the thumb, for example, ordinarily affects the first phalanx. As the movement increases in force the whole thumb is pulled back and the wrist-muscles are innervated to prevent the movement from spreading to the wrist. Again, the short flexor of the thumb not only flexes the nail-joint but also helps to move the entire thumb toward the little finger. And the

chief abductor extends the nail-joint, moves the middle phalanx sidewise and abducts the entire thumb, a combination of functions found also, though of opposite kind, in the thumb-adductor. The thumb muscles are illustrated in Fig. 18, *a*, *b*, *c*, *e*.

Origin and Insertion of the Muscles.

The attachment of the muscular tendon to the rest-end is called the origin of the muscle, and the tendonous attachment to the movable bone is called the insertion. From the description of the muscles, their position and their action, it is obvious that between the origin and insertion of a muscle at least one articulation must intervene. In the case of several muscles more than one joint intervenes. The entire problem of muscular action depends upon the relationship between muscle-position and joint. Accordingly, the question as to which end of a muscle is its origin and which its insertion cannot always be definitely answered until the movement is seen. Muscular contraction through the principle of the opposite equality of forces, will exert a pull on both bones to which the muscle is attached. The bone offering the less resistance will be the one to move. Hence origin and insertion may change places. In general, however, the origin of a muscle will be the end closer to the trunk.

Conclusions

From the analysis of muscle-position and function a number of conclusions may be drawn which have a direct bearing upon the fundamental principles of piano technique.

(1) The simplest muscular movement involves a coördination of muscles. It is a muscular complex.

The mechanical need for this was indicated in the chapter on Mechanics as well as in the paragraphs on skeletal articulation. To infer from the unity of a movement that it must be based upon a physiological unity of muscular action (when determined by the position and contraction of the various separate muscles and not by their coördination) is entirely wrong. The visual simplicity of a movement is in no way correlated with simplicity of muscular action. With the arm in certain positions, a simple straight-line movement of the hand may necessitate movement of the entire muscular system of the arm.

(2) The smallest movement has some "spread". The greater the extent or the force of the movement the greater is the spread of muscular activity.

Every voluntary movement made (excepting those movements resulting from gravity) requires some arm-position, and this, in

turn, requires its muscular "setting". Accordingly, we cannot speak of a definite movement without fixing both its extent and its force. A pianissimo finger-stroke through two inches, is a different muscular reaction than the same finger-stroke producing a forte tone. Movement of the hand through six inches involves a different muscular activity than a similar movement through eighteen inches.

(3) Equal and opposite spatial movements do not, necessarily, mean correspondingly equal and opposite muscular movements.

Raising the arm requires more effort than lowering it, on account of the action of gravity; fore-arm supination covers a wider force-range than fore-arm pronation, because the supinators are more powerful than the pronators. Finger adduction is easier than finger abduction because the fully adducted position (fingers side by side) is the position of normal rest. We may also conclude, conversely, that equal muscular effort may therefore produce unequal forces.

(4) The size and strength of a muscle depends upon its function; that is to say, upon the size, weight, and position of the parts of the body that it moves.

The most powerful muscles of the upper limb are accordingly found in the back and in the chest; the next most powerful in the shoulder; then in the upper arm, fore-arm, and finally, the weakest, in the hand.

(5) The more extended or forceful a movement is, the more necessary is the activity of large muscles.

This is a corollary to the second conclusion on the "spread" of muscular activity. In an extended movement, whether of little or great force, large amplitude must be covered, which depends upon the movements of the large anatomical appendages (whole arm or fore-arm) and hence also upon the use of large muscles. In a forceful movement, whether of little or great amplitude, sufficient rigidity must be present to permit the necessary joints to act as fixed fulcra; hence, here too, the large muscles will be needed.

(6) Absence of motion does not necessarily mean absence of muscular activity.

Two equal forces acting in opposite directions upon the same point will not produce motion at this point, but the forces will none the less be acting. So, antagonistic muscular groups can act equally upon a joint, setting the joint in a fixed position but not producing motion at the joint. (Mechanical Principle, 4.)

(7) No muscle is limited to the production of a single movement. It has a primary function, and always secondary or tertiary functions.

Each muscle is the chief factor in a certain type of movement, but as this type gradually changes into other types the muscle continues to act in a continuously decreasing degree.

(8) Many movements of translation are produced by movements of rotation. The hand may move in a horizontal plane by rotation of the upper arm. The straight finger-stroke may result from rotation (flexion) in the hand-knuckle combined with opposite rotation (extension) at the interphalangeal joints.

CHAPTER IV

States and Properties of Muscles

A MUSCLE is a complex organ consisting of striped muscular tissue, some connective tissue, many blood-vessels, and nerve fibres. Surrounding each so-called muscle is a covering of shiny connective tissue, from which layers extend inward through the muscle dividing it into muscular bundles. These are in turn further subdivided, so that a cross-section of the belly of a muscle gives the appearance of a cellular structure, the cells being filled with the muscular substance.

The fibres of the muscle vary greatly in both length and thickness, in length from a small part of an inch to somewhat more than an inch; in thickness, according to reliable authorities, from one four-hundredth to one seven-hundredth of an inch. Each of these fibres, which form the real muscular substance, is enclosed in a tissue. The function of the latter is to enable the contractility of the muscular substance, which is itself quite soft, to act at the points of insertion, thus producing the desired movement; for the tissue, unlike the muscle fibre which it encloses, is neither extensible nor contractible. When a muscle contracts, therefore, it is the result of the contraction of the thousands of its muscle fibres; and when movement takes place, this results from the transmission of this contraction to the connective tissues enclosing the fibres, and through these and the tendons to the points where the tendons are attached to the bones.

Contractility.

The most important property of muscle is its contractility. When appropriately stimulated, the muscle fibres contract and pull upon the inelastic tissues surrounding them. It is customary to divide muscular contraction into two types: a single, momentary contraction, known as a "twitch", which is always involuntary, and a more or less sustained contraction, known as "tetanus". In all voluntary movements the reaction, no matter how short, is tetanic in character. It is not produced by a single momentary stimulus but by a series of such stimuli. Since piano-playing is concerned entirely with voluntary movements or movements that were voluntary before repetition relegated them to the reflex field, the analysis of the simple twitch contraction need be but briefly treated.

In neural stimulation the impulses reach the muscle fibres at intervals shorter than the time needed for the muscle to return to its original state. As a result, summation of contraction takes place. The chief characteristic of this summation is that it exceeds the maximum contraction possible with a single stimulation. Its greater duration of contraction is obvious, since the movement is the response to a series of successive stimuli.

The contractility of a muscle varies further with the intensity of the stimulus. A very weak stimulus may be insufficient to produce any movement. As the intensity of the stimulus increases a point will be reached at which slight contractions occur. A further increase in intensity will result in an increase in contraction. In voluntary movement it is difficult to reach a complete maximum because the nature of the stimulus is psychological, and depends upon such unstable factors as the will, besides being dependent upon circulation and respiration.

Muscular Action

Simple Contraction (Twitch).

The simple innervation of a muscle results in an activity which may be divided into three parts : latent period, period of contraction, and period of relaxation. A muscle, scientifically speaking, does not contract simultaneously with the stimulations, but about one-hundredth of a second after stimulation. This latent period, however, is, for our purposes, negligible, the time involved, even if it were considerably longer, being well below any time-value used in piano-playing. The periods of contraction and relaxation vary greatly with the condition of the muscle and the particular muscle used. A fixed time for all muscles cannot therefore be given, although normally both phases occur in a very small part of a second. Any twitch, however, takes less time than any isolated or repeated movement demanded by piano-technique. Consequently, the contractile speed of a muscle, or more accurately, the lack of it, cannot account for any difficulties in muscular action as applied to the piano. Normal muscle can contract and relax with sufficient speed to meet any needs of the pianist. In a simple contraction, generally termed " twitch ", a muscle does not shorten more than one-fourth of its total length.

Complex Sustained Contraction.

The muscular " twitch " just described plays an insignificant part in the voluntary action of muscles. Its physiology has largely been determined by the electrical stimulation method on the excised muscle.

If, instead of a single stimulus, a series of stimuli in rapid succession be used, so that the second stimulus arrives before the effect of the first stimulus has worn off, we get, instead of a series of separate contractions, a sustained contraction known as physiological tetanus. The muscle remains contracted and shows a condition which we should expect if the stimulus were continuous. Moreover, in tetanus, the muscle shows a greater degree of contraction, a more powerful contraction, than in simple stimulation. This is but another example of the principle of summation of stimuli.

All voluntary movement is tetanic in character. The very shortest voluntary contraction is not induced by a single neural impulse, but a rapid series of such impulses. This is a fundamental characteristic of the neural current. The resulting action of the muscle, therefore, though in appearance a single unit of movement, results from the application of a series of stimuli. The shortest *staccatissimo* is not an exception. The reason for this speed of neural stimulation is found in the rate of the motor nerve, which has its own speed of neural discharge. Since this rate is physiologically predetermined and beyond our control, the fact that every voluntary or habitual movement is tetanic has no further direct bearing upon our problem.

Degrees of Contraction.

A contraction may be the result of either of two muscular conditions : first, all the muscle fibres may contract to a moderate degree, producing, by their summation, a force effect ; secondly, some of the fibres may contract strongly, and the others remain passive, producing the same force effect. The former view would demand a nerve impulse to the muscle as a whole ; a form of mass-action rather at variance with the essentially integrative action of the organism. In support of this view is the evidence produced by experiment upon the excised living muscle of the cold-blooded animals. In these cases the degree of contraction of the muscle depends upon the intensity of the stimulus, an increase in the stimulus producing an increase in contraction up to a point beyond which the muscle does not contract. Since the electric current used for stimulation may reasonably be supposed to traverse the entire muscle regardless of the intensity of the current, this phenomenon of graded response supports the first view that in any muscular contraction all the fibres are contracted, their degrees of contraction varying with the stimulus.

A second, somewhat more promising view, holds that as the

stimulus increases in intensity new fibres are added to those already functioning, thus changing the total response without changing the response of the original fibres. This view, of course, is in close agreement with the commonly observed "spread" of muscular activity with an increase in the stimulus. It seems probable, therefore, that both reactions actually occur in any movement of sufficient variation. Experimentation upon the excised muscle has shown that a single muscle can give graded reactions. When such a muscle is attached to a complex leverage system, like that of the arm, any variation in the force-effect of its contraction will be communicated to its origin, upon which this force will work. Accordingly, the muscles controlling the point of origin will have to contract in proportion to this increase in force, and the muscular spread is the result.

This leaves the graded response within a single muscle to be explained. Do all the fibres contract in response to every stimulus, varying in their degree of response, or does the number of reacting fibres increase with an increase in the stimulus ?

Exercise does not increase the number of muscle-fibres, but increases the size or growth of the fibres themselves. That is to say, a muscle grows, gets stronger, not by the addition of fibres to others, already present, but by an increase in the size of the existing fibres. This points to a physiological unity of muscle which would support the total reaction theory. The presence of a nerve fibre for each muscle fibre is itself not decisive in either way. Such an arrangement would be as useful for total response as for partial response. The question cannot, at present, be answered definitely, facts being deducible in support of either theory.

Graded Response.

Be that as it may, the piano teacher need not wait for its solution. For him, the important phase of muscular contraction is that graded reaction actually exists, and that the degree of response varies directly with the intensity of the stimulus. We know, definitely, that graded response is possible either by gradations in the reaction of a single muscle or by a coördination between muscles.

In the chapter on Mechanical Principles, a force was shown to depend upon the speed and the mass of the moving body. So long as the number of muscles acting at any one time remains a constant (these, with the weight of the moving part constitute the mass), variations in force can result only from variations in speed or acceleration, since the force equals the product of the mass and the acceleration. Accordingly, if an increase in the force of

a movement be desired without changing the extent or spread of the movement, the speed of the moving body must be increased. And conversely, with the same speed, the same muscle can only produce one degree of force.

A second factor in grading muscular response is the form or shape of the muscle itself. The force which a muscle exerts is the result of the size and the number of its fibres ; the distance through which the muscle contracts is the result of the length of the fibres. Its force is measured by its cross-section. When the distance through which the muscle acts is a constant, the amount of work done, that is to say, the force of the contraction, is determined by the thickness of the muscle, thickness being the dimension at right angles to the direction of the tissues and fibres. When force is constant, the distance through which the muscle can move a body depends upon the length of the muscle. Short thick muscles function best for short, powerful, movements ; long, thin muscles, for less powerful, more extended movements.

When both an extended and powerful movement is executed, this demands a coördination of muscular action in which each muscle contributes its efficiency to the efficiency of the whole movement. This is discussed in detail under Coördination. It follows, if a short, powerful movement be desired, that muscles must be innervated to augment the thickness sufficiently ; or else that certain other muscles, themselves thick, must be used. A movement, therefore, made slowly and then made rapidly, cannot involve the same muscular response, since greater force is required for the greater speed.

Thus, apart from effects of temporary and permanent physiological condition, the strength of a muscle depends upon the size of its cross-section. A thick muscle is more powerful than a thin one, other things equal. The extent or range through which a muscle acts depends upon the length of the muscle, greater length naturally permitting more extensive contraction. A powerful muscle thus has a wider range of gradation than a weak muscle, because it may continue to function when the weaker muscle has already used all its force. The question now suggests itself : To what extent are powerful muscles desirable in piano-playing ?

Any increase in dynamic range of action is desirable because it gives the player command over a greater variety of technical response. Not only does the muscle itself permit this increase, but the possible combinations with other muscles are likewise increased. Experiment has shown, generally, that a muscle does its best work with relatively light loads, although some investigators

have found maximum efficiency at half the maximum load. Accordingly, if work of eight units is to be done, a muscle capable of twenty units, will do the required work with greater ease and less fatigue than a muscle whose maximum power is ten units. An increase in power is not, in itself, accompanied by loss of sensitivity to fine adjustments. The fact that the latter frequently accompanies the former results from the increase in tension which heavy work necessarily requires and from the added flesh resistance which accompanies muscular growth. The more powerfully we play, the greater must the articular tension be in order to meet the increased resistance. But tension, as we shall see, precludes accurate judgment of resistance, and, upon such judgment, all tonal effects on the piano depend. Mere increase in muscular strength, therefore, has its undesirable as well as desirable results, so far as its application to piano-playing is concerned. Only when the increase in strength reaches a point at which, for the reasons given, it interferes with flexibility and finer adjustment, does it become undesirable. The normal pupil seldom reaches this point. A few illustrations will make this clear. A composition such as the Liszt B-minor Sonata, apart from any technical demand of dexterity, requires a considerable output of pure physical force. If the player possesses sufficient strength in fingers and arms, he can distribute this in any of several economic ways. The player with weak fingers and arms, on the contrary, will have to be satisfied either with less pronounced dynamic effects, or with the utilization of the shoulder and back muscles, a coördination that does not always facilitate the technical demands of the particular passage.

Similar conditions hold for compositions demanding sustained finger-work. If the fingers be sufficiently strong, the required dynamic gradations may be made without calling into play the larger muscle-groups of the arm. In passages in which held notes against trill figures make arm-movement awkward, if not impossible, sufficient finger-strength is absolutely necessary, particularly if dynamic gradation be desired. In this connection a spread to the arm is often considered poor coördination, something to be avoided. But is not the spread nature's device for reënforcing the fatigued finger muscles with the arm muscles? At least, we never meet this muscular "spread" in similar short passages, or in strong fingers, where in both cases it would be reasonable to expect it, were mere incorrect coördination the cause.

Muscular Work.

The mechanical principle of work states that the work done equals the product of the force and the amount of displacement. Applied

to the muscles this equals the force of contraction and the longitudinal extent of contraction. Since the force with which a muscle contracts depends upon the thickness and the number of its fibres and the distance through which the muscle contracts depends upon the length of its fibres, there is no constant for the force effects. For the extent of contraction it is safe to say that a healthy muscle fibre can contract to one-half its original length.

Two muscles of radically different sizes can thus perform equal amounts of work, though they do not do this in the same way. Suppose the force exerted by a thick muscle to be 10 lbs. and of a thinner muscle, 5 lbs. If the thicker muscle lifts a weight through 2 in. and the thinner muscle lifts it through 4 in., they will have done equal amounts of work: 20 work units each.

Temperature.

The efficiency of muscular action is also affected by temperature. In the warm-blooded animals temperature effects are minimal since the bodily temperature, regardless of that of the surrounding media, is practically a constant. None the less, the piano teacher is frequently confronted with conditions produced by temperature deviations. The general stiffness of the early morning pupil, the cold, perspiring hands of the anemic one, are examples of the temperature effects of poor circulation at the extremities of the body. Since this is essentially a circulatory problem, it will be discussed in Chapter V.

Fatigue.

The earliest onset of muscular fatigue affects the relaxation, not contraction rate of the muscle. The muscle fails to relax as rapidly as at first, with the result that the second stimulus may come before the effect of the first stimulus has been neutralized. The next effect of fatigue shows in the degree of contraction. The muscle contracts less and less to a stimulus of uniform intensity, which, if sufficiently prolonged, will finally result in absence of any contraction.

Muscular fatigue is a chemical process, an accumulation of waste products (carbon dioxide, lactic acid, and others) in the muscle. The removal of these is normally done by the circulation. When the accumulation of waste products exceeds the rate of their removal and the rate of replenishing with efficient substances, fatigue sets in. If, before complete fatigue, a short rest period is allowed, the muscle shows a rapid recovery, since the waste products can be removed quickly, once activity ceases. However, if forced contraction be resorted to, when a muscle is already well fatigued,

a much longer period of rest is needed for it to regain its contractility. Muscular action, therefore, should not be carried on after moderate fatigue is present.

In spite of popular opinion to the contrary, experiment has shown that fatigue in one set of muscles decreases the energy output of other sets. The flow of blood with its fatigue products accounts for this. Accordingly, the most efficient muscular activity is the first activity preceded by a moderate "warming-up" after relatively complete muscular rest. When we change from one hand to the other in piano practice, without complete rest periods, each successive attempt is muscularly less efficient. This, of course, is to be understood strictly physiologically. Improvement of coördination resulting through practice, readily outweighs the slight loss, if any, of muscular contractility. Moreover, unless the rate of muscular stimulation exceeds the rate of waste-product removal, no fatigue is present. In normal piano practice, the pupil not only does not exceed the muscular fatigue limit, but probably never even reaches it.

Sensations of fatigue are localized in the region of the affected muscles, not in the joints. The location of the fatigue sensations is thus an index to the muscle that has been active. A pupil with whom I was working for arm-relaxation, complained of fatigue in the deltoid muscle. Nothing in the outward movement of the arm had caused me to suspect arm-abduction. Once, however, this antagonistic muscular activity was revealed, she had no difficulty in relaxing. It is pedagogically advisable that each teacher become personally acquainted with the sensations resulting from muscular fatigue. This may be done in various ways. Prolonged activity in any unusual form, bowling or tennis, is a good example and will rapidly produce fatigue. If an ergograph is available, fatigue of any finger muscle can readily be recorded as well as felt. The sensation of fatigue, as we should expect, is not a sharp pain, but rather flat or diffused. It is, in consequence, often localized with difficulty by the young pupil who describes it as "just generally tired", "feel it in my whole arm", "can't say just where it is."

Rigidity.

Physiological rigidity may be divided into two classes: that resulting from excess lactic acid production, the most marked instance of which is *rigor mortis*, and that resulting from simultaneous contraction of antagonistic muscle groups. In discussing joints and muscles we learned that most movements, at least in their component parts, involved the activity of opposite muscle-

groups, one of which contracted while the other relaxed. We know that, normally, with every impulse to a flexor to contract, goes an impulse to the corresponding extensor to relax. That is to say, such is the case if movement (in this case flexion) at the joint be desired. But if movement at a more distal joint be desired, or some other powerful resistance is to be overcome, flexors and extensors are simultaneously contracted, thus setting the joint firmly against movement, and enabling it to act as a necessary fixed fulcrum. The degree of rigidity depends upon the degree of simultaneous contraction. Mechanically, the articular surfaces of the joint are firmly pressed together because the simultaneous pull of the muscle tendons forces the distal surface firmly against the proximal surface.

Such a condition, since it is necessary in some degree at all joints in order for any movement to occur, involves no undue or unnatural strain upon the organism or any of its parts. If the back of the hand were not held fixed (by appropriate fixation of the wrist) as the finger-tip strikes the piano-key the hand-knuckle would be pushed up. In order to permit maximum functioning of the finger-tip, the knuckle must remain fixed during the movement. This rigidity, since it is constantly in operation in all movements, is not felt as rigidity or stiffness, because its degree is favourable for the proper execution of the movement and hence aids, instead of interferes with, the coördination. Only when rigidity reaches an unnecessary degree, or when it is unnecessarily present in some joint not acting as a transmission-point for the force, does it constitute what the piano teacher calls "stiffness". If the tension in a joint exceeds the amount of resistance which the movement is to overcome, this excess is wasted effort and serves no physiological purpose. Unless extreme, it will not make itself quickly felt, nor will it seriously interfere with the execution of the movement so far as this merely overcomes a resistance. On the other hand, if the rigidity is present in a joint where movement would facilitate the total action, the condition seriously interferes with the ease, accuracy, and speed of the movement. It interposes an additional, often very considerable resistance, which hastens the onset of fatigue and often directly interferes with the proper movements in related parts. Since, however, the efficient amount of work done by any muscle is not increased, the fatigue, or more accurately strain, is not a condition in the muscle, but in the joint, where the simultaneous contraction of the antagonistic muscles exerts supernormal pressure between the two articular surfaces. Sensations of strain or rigidity, therefore, are referred to the joints. The joints cannot

fatigue in the sense of the muscles, because there is no organ at the joint for activating work. Fatigue sensations localized in the joints result not from muscular fatigue but from inappropriate joint-rigidity. They are always, with a few exceptions in extreme performances, undesirable in piano-playing because they tend to destroy the correctness of the movement as a whole, and because they make judgments on extent, degree, and direction of movement more difficult.

Muscle-Tone.

Between the finer fibrils of the muscle fibres are minute spaces filled with a semi-fluid substance called sarcoplasm. The actual muscular movements are made by the fibres, the changes in the general condition or "tone" of the muscle, as it is called, are generally attributed to the sarcoplasm. Inability to write smoothly after a hard set of tennis or other muscular exercise, inability to prevent excessive movements after an hour of strenuous physical culture, and the tenseness of the muscles as a result of emotional excitement, are generally considered examples of changes in muscular tone. Paderewski's signature after a strenuous programme illustrates the effect. A distinction should be made here, however, in the last-named instance. If the tenseness is present during the emotional excitement it is probably a real muscular contraction, a reflex resulting in a heightened efficiency to respond to any sudden stimulus. It puts the person on the "qui vive". It is only indirectly, therefore, a change in muscular tone. If the tenseness in the muscles persists, or if its reverse, a hyper-relaxation, sets in after the excitement has passed, the condition does show a change in muscular tone.

Since, however, the tenseness during excitement is uniformly a reflex, it has been customary to speak of this tenseness as heightened muscular tone. On this basis muscular tone is greatest during any form of strenuous exercise or intense emotional strain, it is less during periods of relative inactivity, and it is least during sleep or the influence of anesthetics. The close relationship between what is called "tone" and the property of relaxation will become evident with the analysis of relaxation.

Relaxation.

The salient feature of modern piano pedagogy is the stress placed upon relaxation. As a result of wide-spread use of this term not a few discrepancies and misconceptions have arisen. These make necessary a detailed analysis of this property of muscles.

For the sake of clearness, I shall for the present exclude the

influence of nerve impulse upon muscular condition, and treat the muscles as physiological entities. This is, of course, not the condition under which they operate in life, but it at least will permit a clear exposition of the state of relaxation. The effect of the nerve impulses upon this state will then be treated under Coördination and Incoördination.

The property of muscle-tone exerts a force at each joint relatively constant for each muscle or group of muscles. Accordingly, a completely "relaxed" joint does not exist anywhere in the human body. I use "relaxed" here in the sense of zero resistance. No two bones, during life, normally rest loosely upon each other at a joint; there is always pressure of one articulating surface upon the other. Since this, in a degree varying with the growth of the organism, has been present in all joints from birth, we are not aware of this force or of its effects, and what the mind considers complete relaxation, in the absence of any sensation to the contrary, is not complete physical or physiological relaxation.

This normal joint-resistance, instead of a zero-point, must form the basis of an analysis of relaxation. We begin, not with a flabby muscle, but with muscles possessing a certain pull. For the sake of simplicity a hinge-joint with two antagonistic muscles may serve as the first illustration. Suppose the normal muscle-tone at the joint to be 100 force-units, the actual force value in ounces or pounds being of no consequence in an exposition of the principle involved. Such a joint will be relaxed so long as this norm is not exceeded. If either muscle, or both muscles should relax to a point where their summated pull is below this norm, a condition of "looseness" at the joint results, the bones now being held in place more by atmospheric pressure, by the fleshy parts surrounding the joint, and by the formation of the bony surfaces. In such a condition, for example, the head of the humerus can be pulled out (by external force) over an inch from its socket in the shoulder. If both muscles now contract beyond the normal tone-state, the pressure at the joint will exceed 100 force-units and the condition of "stiffness" results. (It is necessary to point out here that although we speak of a "stiff" or "relaxed" joint, in reality it is the muscles controlling movement at the joint that cause the stiffness or relaxation at the joint itself.)

These conditions or variations in resistance are adequately studied by the action of the apparatus represented in Fig. 19. This consists of three scales, one opposed to the other two, in order to register the pressure upon them as the pull of the other forces increases or diminishes. The levers represent the bones, *m*, the

joint, the balances B and C represent the muscles, and the strings leading from the scales to the points of insertion represent the inelastic tendons. The pull of the two balances may be considered

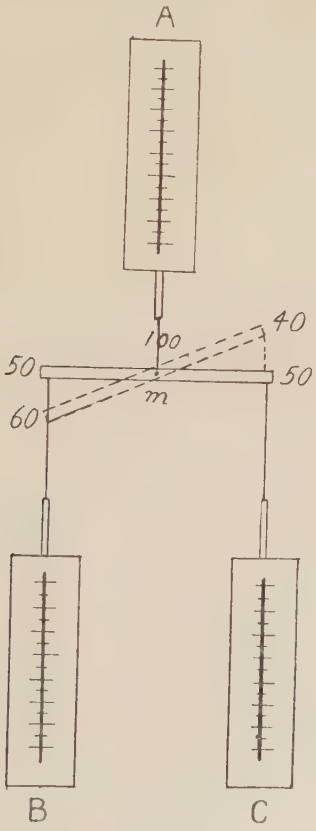

Fig. 19.

the normal muscular tone and this will register on A. Suppose each muscle to exert a force of 50 ; then, in a movement, perfect, not complete or zero relaxation, occurs if, when muscle B exerts a force of 51, muscle C exerts a force of 49 ; when B pulls with 60, C pulls with 40. In other words one muscle relaxes at precisely the rate at which the antagonistic muscle contracts. As a result no work is wasted, *m* remains stationary, and the contracting muscle does its work with no more than the normal joint-resistance. By moving B and C in opposite directions, keeping the registration on all three balances stationary, the ease of a relaxed movement is readily felt by the person moving the balances.

Now suppose muscle B to relax at a rate greater than the contracting rate of muscle C, so that, for example, B exerts a force of 30 when C exerts a force of 60. The total joint pressure is now 10 below normal, resulting in a small degree of "looseness", with its consequent impairing of accurate control, and balance A will record the drop in tonus as *m* ascends. Such a condition is found in the high degrees of bodily relaxation, as in sleep. If, in a waking condition, we are asked to respond to a stimulus, we do so with a muscular reaction much greater than that necessary for an adequate reaction. This excess results from the lack of control over movement when the joints are in a state of hyper-relaxation. This condition, therefore, is not the most desirable one for voluntary movement. It is useful for emphasizing the feeling of relaxation in certain subjects, but it is never used in actual piano-playing, in spite of the wide-spread notion that it is so used. Illustrations of its presence are found in the passively swinging, pendular arm while walking, and in the dangling hand while resting the arm on a table or on the side of a chair. There is, in these cases, a certain amount of "slack" to be taken up before the normal resistance is reached, upon which the adequate control of movement depends. A helpful analogy to the physiological state of hyper-relaxation is found in any system of compound levers permitting "play" at each joint, as a result of which accurate operation cannot begin until this play has been overcome. Such a mechanical scheme is obviously not adapted to accuracy or speed.

The third typical muscular state is that of hypo-relaxation. It results when one muscle relaxes at a slower rate than that at which the other muscle contracts. Beginning again at the normal tension of 50 for both muscles B and C, if B increases its pull to 70 and C relaxes to 40 instead of to 30, we have a plus resistance of 10, which interferes with the freedom and maximal efficiency of the movement, and *m* will move down, registering this plus resistance on A. This condition is popularly termed stiffness or rigidity, and its eradication forms one of the most important problems in piano pedagogy. A similar, although not entirely parallel, instance in mechanics is the operation of any rusty or non-oiled hinge. Much more force is required for the desired movement than that used when the friction between the parts is reduced by cleaning and lubricating. The added resistance can be felt when the balances of Fig. 19 are so moved.

The classification of the relaxation states into hyper-, normla, and hypo-relaxation shares the disadvantage common to all similar classifications. This is their failure to indicate the many inter-

mediate states, in consequence of which any one state may be made to grade by imperceptible plus or minus increments, into the next state. Thus if normal relaxation is at a combined tension of 100, distributed for muscles A and B at 50 each, then a contraction of A to a tension of 60 and a relaxation of B to 41 adds but one one-hundredth to the normal tension. If B relaxes to 42 the hypertension is two. A movement in this condition is quantitatively practically normal relaxation. Accordingly, the degrees of relaxation are not marked off by clearly defined types, but may shade by continuous transition from an approximate zero to an approximate hundred per cent relaxation.

The illustration given, limiting the muscular action to two muscles with equal normal pull cannot be applied in this simple form to any complex movement. As we have seen, even the smallest bodily movement is a muscular complex, involving movement or tension at more than one joint, and muscles at various and varying tensions. This complexity, however, does not create any new principle of reaction, but merely extends the simple mechanical principle that we have considered to several muscles and joints in simultaneous operation. When such an action takes place without unnecessary friction, and maximal efficiency, it is spoken of not as a relaxed movement (although this term is applicable), but as a coördinated movement ; and when excessive friction or looseness interferes with the efficiency of the movement, it is said to be incoördinated.

CHAPTER V

The Neural and Circulatory Systems

Neural System.

In combining the two remaining systems that make up the physiological organism there is danger that their importance, particularly that of the nervous system, may be underestimated. In piano-playing the whole learning and playing process is inseparably bound up with nerves and their centres: the spinal cord and the brain. But the study of these phases is primarily a psychological problem, and I wish, so far as possible, to limit the present investigation to the mechanical and physiological fields, particularly the muscular fields. Accordingly, a brief exposition of the various parts of the nervous and circulatory systems, and of their principles of operation, must suffice.

The functional unit of the nervous system is the nerve cell or neuron. Of this there are three kinds: sensory, motor, and intercalated. The sensory cells bring the neural impulses in from the sense organs, the motor neurons carry the impulses out to the muscles, and the intercalated cells join, in a very elaborate scheme, the cells of the other two groups. The three groups are also called receptors, effectors, and conductors, respectively. Thus we have the three fundamental requirements of a nervous system: a means for registering impressions from the outside world, a means for conducting, transforming, storing, and elaborating them, and a means for expressing through movement, these impressions, memories, and elaborations.

The spinal cord has, as one of its chief functions, the care of reflex action. By reflex action is meant a response of the organism not involving consciousness or the interposition of a brain. Moreover, since the efficiency of reflex action depends upon speed, it is not surprising to find sensory and motor paths, which lead to the same bodily region, entering and leaving the spinal cord in close proximity to each other. This topographical relationship applies to the general regions also: the centres for foot and leg are in the lower region of the spinal cord, those for hands and arms in the upper region.

The second function of the spinal cord is its connection with the brain, as a result of which volition can at any time stop the reflexes or modify them. But more important still is the fact that by repetition

of voluntary movement, which must always begin under direct brain control (if pupils only realized this in early stages of practice !), the brain is needed less and less until, finally, it is relieved of all participation and we have what is known as an acquired reflex, the work of the spinal centres.

In thus speaking of nerves entering and leaving the cord one must not think of a small number. Ingbert counted approximately six hundred and fifty thousand fibres, in the dorsal roots entering one side of the spinal cord. The diameter of these fibres varies ; the thickest does not exceed one two-thousandth of an inch.

The brain itself is, for the psychologist, the most interesting part of the nervous system. Of its five parts the cerebrum and the cerebellum are the most important for our purposes, since it is these parts that are chiefly concerned with learning in all its forms. The cerebellum, or small-brain, acts as a reflex centre for posture, muscular tensions, movements and external strains. To these belong the sensory impulses arising in a muscle when it contracts passively as a result of the action of external forces. Injury to the cerebellum is similar to injury to the semi-circular canals of the ear ; both are followed by loss of sustained posture and muscle tonus.

These various parts of the nervous system are connected in many ways by the nerves of popular terminology. In the case of the arms, the sensory pathways enter the spinal cord by the dorsal roots, some passing directly to the ventral horn, others continuing up through the cord to the bulb (base of the brain), thence to the thalamus, where new cells arise and lead to the cortex of the cerebellum. Thus at least three sets of fibres must be innervated before a sensory impression from the arms (legs or trunk likewise) can reach the brain proper.

Similar conditions exist for the ear and the eye. These, with the hands and arms, form the working material of the pianist. The motor tract in turn leads from the motor area of the cortex to the muscles, by way of the bulb and spinal cord. In the latter the fibres connect with the motor cells which carry the impulses to the muscles. This is the outgoing phase of the mechanism of voluntary movement. The inter-connections of the motor tract point to a close association with the purely reflex arcs. This is to be expected, for in most, if not in all voluntary movements, reflex elements are present.

All this specialization of functions which we have just considered would serve no biological value if it were lost entirely upon reaching the brain. And, as a matter of fact, it is not lost. The cerebrum itself, although in external appearance a well-defined anatomical

unit, is subdivided into areas specifically connected with, and reacting to definite sense departments. Thus we speak of a motor area, auditory area, visual area, and others. This is not supposition, nor has it anything to do with phrenology. Evidence is furnished by direct experimentation (not only in the lower animals and anthropoid apes, but also on man), by human pathology and by comparative anatomy. When certain areas of the brain are directly stimulated, sensations and movements result, corresponding to the area stimulated, and these responses are absent if other areas are stimulated. Disease in a certain area will result in loss of sensation or movement for that field, a loss that extends even to memories and ideations. Finally, comparative anatomy shows that high development in any capacity is accompanied by high development in the corresponding cortical area. This, however, is something far different from the knowledge bumps of the phrenologists.

The various sensory areas and the motor area do not, however, make up the entire cortex of the cerebrum. Connecting these areas are others, generally termed the " silent " or " association " areas of Flechsig. Their function seems to be connection among the various sensory areas, and between these and the motor area.

Every sense department, accordingly, is brought into more or less direct contact with every other department. The silent reading of the word " orange " may initiate the speech muscles into saying the word ; may recall the visual image ; may call up the aroma (olfactory stimulation), and the taste (gustatory stimulation) ; may arouse the " feel " of the fruit (cutaneous) ; its weight (muscular) ; finally, even the sound of the spoken word (auditory). If it were not for the association fibres, such a response would be impossible.

Integrative Action.

The arrangement of such a system is obviously integrated or coördinated action. No part does any work without at least the possibility of affecting all other parts. Even the acquisition of a highly specialized reaction is largely the exclusion of other co-related reactions which would be possible on account of the inter-relations among the parts. The higher the specialization, the finer were the associations that made it possible. Thus the nervous system, like the skeletal structure and the muscles, is fundamentally opposed to fixed, isolated response, and represents, instead, the highest type of adaptation or changing response.

Circulatory System.

The effects of the circulation upon piano technique are somewhat less important than those of muscular construction and function

which we have considered. The effects, however, are of sufficient frequency and range to warrant an inclusion, at this point, of a brief survey of this fourth part of the human organism.

The Blood-Vessels.

The blood-supply for the arm is furnished by an intricate system of blood-vessels, with the axillary artery, situated in the shoulder region, for their fundamental source. This artery has six branches, each of which again subdivides into smaller arteries. The main artery of the upper arm is the brachial artery which runs along the inner side of the arm. It gives off five branches, some leading to the muscles and others, the nutrient, to the tissues. Immediately below the elbow this artery divides into two branches, the radial and the ulnar, extending along the similarly named bones. Branches from these arteries feed the muscles of the fore-arm. After various divisions one branch of the radial artery, after passing under the muscles of the thumb, unites with the deep branch of the ulnar artery. From this point arise the smaller arteries of the hand and fingers, the arterioles, and, finally, the capillaries.

In general, paralleling this system of arteries is the venal system carrying the blood back to the larger veins and thence to the heart. At the points where this transfer is made are the capillaries, myriads of fine, microscopic tubes connecting the arterioles with the smallest branches of the veins. Their walls permit the passage of nutrient substances from the blood to the tissues and that of waste products back into the blood. Capillaries are arranged in fine network formation, the character of which differs in various tissues and in individuals. By means of the capillaries, blood reaches practically every part of the body. The average diameter of the capillary is considerably less than one one-thousandth of an inch.

The Circulation.

The function of the circulation is to supply nourishment to the tissues of the body, to remove waste products, to supply sufficient heat and remove excess heat, and so guard against infection. In discussing the muscles we learned that their adequate functioning depended upon adequate blood-supply. Consequently, irregularities and other abnormalities in the blood supply interfere with muscular reaction, and through it, with movement. Four factors determine normal blood-flow: heart-beat; resistance to blood through sides of vessels, especially peripheral resistance in narrowness of the small arteries; elasticity of the arterial and the venal walls; and quantity of blood in the system. Variations in the blood-flow are caused by an increase or decrease in the rate

and force of the heart-beat ; increase or decrease in the size of the blood-vessels ; constriction and dilation resulting from the operation of the vasomotor nerves ; diminution of elasticity in the vessel walls, the hardening of the arteries as in old age ; loss of blood through disease or injury ; respiration and gravity. The maintenance of high arterial pressure is the chief function of a normal circulation.

Effect of Circulatory Variations.

Deficient blood-supply will make any movement less smooth or less efficient than normal blood-flow. In the first place it impoverishes the sensitivity of the nerve endings ; it likewise reduces the speed and accuracy of muscular contraction. As a result the best muscular reaction to a touch stimulus cannot be made. Examples of such conditions are readily given : the " warming-up " of the pitcher in base-ball ; the swinging of the arms in cold weather, the playing of a few chords, or arpeggios, by the pianist, preliminary to the beginning of the actual program ; all these are done for their effect upon the circulation. The " stiffness " of early morning is less joint than muscular, and in turn, circulatory stiffness.

Cold weather drives the blood from the peripheral vessels to the more vital internal regions, where maintenance of a constant temperature is necessary : a device of biological economy. As a result, the finger-tips are the first to become affected by cold. When the withdrawal of blood is sufficient, a state of complete numbness (" numb with cold ") may result, in which all touch sensations at the finger-tips are lost. The fingers become " stiff ", that is to say, their free and skilled movements are interfered with. In the finely skilled movements used in piano-playing even a slight interference is sufficient to hamper an adequate performance. In fact, just because these interferences are so often minute, they escape detection and the resulting awkwardness is attributed to other causes. Pupils not infrequently lose from five to fifteen minutes of a half-hour piano lesson before circulation has been sufficiently established to " limber up " the fingers. When this recurs at each lesson throughout the winter months, the amount of time lost is a serious item in determining the progress for that term. It not only consumes valuable time but also affects the pedagogic method, inasmuch as it makes postponement of work necessary.

The effect of impaired circulation upon the mechanics of physiological movement is two-fold : it impairs both speed and accuracy.

Speed depends upon the readiness with which the muscle reacts to a stimulus, and, since this reaction in turn demands adequate blood-supply, with equally adequate removal of waste-products, prompt reaction with subnormal circulation is not possible. Accuracy, measured here by spacing and dynamic control, likewise depends upon the sensitivity of the touch-organs and other kinesthetic stimuli. This is the function of the nerves, which can only transmit the impulse they have received. If the latter be deficient, the transmission will be deficient. Especially the finger-tip, that is, its fleshy part, is rich in end-organs of touch. The corresponding intricate capillary arrangement will cause even slight circulatory changes to affect this part, whereas similar quantitative changes would leave other parts unaffected. The fingers and finger-tips are essentially organs for fine adjustments, and are, accordingly, the first to feel small physiological changes.

Since the piano teacher, unless he be also a trained physiologist, should not undertake to correct any pathological condition, most of the problems presented by variations in circulation are outside of his field. Some general suggestions, however, may be found helpful.

Any harmless device that will increase the circulation is useful. Swinging the arms into a position across the chest, sending the blood to the finger-tips through centrifugal force is good ; rubbing the hands together, or against some soft surface so as to produce heat ; washing the hands in warm water will help sometimes, although not always. Timing the lesson arrival ten or fifteen minutes before the scheduled time, thus allowing time for warming the fingers is, perhaps, the best plan. Any form of muscular activity, particularly that using the arms, hands, and fingers, will increase the blood-flow to these parts. This may also be accomplished by stooping well forward with arms hanging vertically, in which position gravity will send the blood into the fingers.

Duration of Variations.

Variations in blood-supply fall into one of two classes : temporary deviations from the norm, caused by conditions immediately preceding the variation in blood-supply; and more permanent deviations caused by some pathological defect. The temporary deviations can be corrected by appropriate exercise ; the pathological condition needs medical attention. One very interesting example has come to my notice. It was a rather pronounced case of Renaud's Disease. Circulation, as soon as the weather became reasonably cold, stopped at the metacarpo-phalangeal joints.

leaving all the fingers bloodless. The greenish-white pallor of the fingers contrasted sharply with the normal colouring of the body of the hand. Naturally all sensitivity of the fingers was lost; a deep pin-prick would cause neither pain nor a sign of blood. Piano-playing was impossible because the finer finger-movements could not be executed. The fact that it was impossible to know when the finger touched the key did not disturb as much as might be supposed. This is because our kinesthetic sense depends much more on sensations of strain and muscular position than upon pure cutaneous sensations. In the case cited vigorous rubbing of the hands re-established circulation sufficiently, but not until a material part of the lesson-time had been consumed.

Causes of Circulatory Variations.

Variations in blood supply may affect either the quality or the quantity of blood and lymph or both. They are caused by the condition of the blood itself; the condition of the heart, arteries, capillaries, and veins; distribution of the blood vessels; posture of the body; exercise; general bodily condition.

The condition of the blood, its percentage of leucocytes, phagocytes, platelets, and lymph determines, among other things, its specific gravity and fluidity, its clotting coefficient and chemical value in nourishing the tissues and removing waste-matter from them. The condition of the heart, its readiness to respond to variations in the intensity of demands made upon it and the contractility of its muscles, together with the functioning of its valves, determines the amount of blood sent to any part of the body within a given time and hence the nourishing value of the circulation. The condition of the blood-vessels, the permeability of the capillary walls, the contractility of the arterial and venal walls as well as their pliability determines the amount of nutrition reaching the tissues and the rate of blood-flow. A rich network of capillaries insures an even distribution of blood for all parts of the body thus supplied. This, in turn, results in added nutrition and improved response of nerves and muscles.

Thus is the efficiency of muscular reaction bound up intimately with the circulation in the body. As a result, the mechanical process of transferring a neural stimulus into an objective force-effect is not a simple cause-and-effect relationship. But the fact that the relationship is highly complex does not invalidate a mechanistic explanation. The real teacher, of whom there are, unfortunately, relatively few, will not rest content with a casual "that pupil simply is not talented", but will seek to find the causes of the

defective playing. This he can do only if he knows thoroughly his tools, and these include the elements of circulation and nerves as well as of the bones and muscles.

Conclusions

1. The value of repetition and drill is to transfer the neural representation of a movement from the higher brain centres to the lower spinal reflex centres. Repetition—normally manifold—is thus physiologically necessary in piano practice, and no adequate substitute for it exists.

2. The whole neural system is opposed to isolated or disintegrated action. The smallest movement of piano technique, as used in actual playing, involves, actively or passively, the trunk as well as the arm, hand, and fingers.

3. Piano technique, for its adequate acquisition, demands a coördination, not only among the organs of any one sense-department, but among the various sense-departments as well: auditory, visual, and kinesthetic.

4. Efficiency of bodily movement, including the fine movements used in piano-playing, is directly connected with a particular area of the brain known as the motor area.

5. Efficiency of bodily movements, especially the fine movements of piano technique depends, in part, upon the condition of the circulation. An adequate blood supply to nerves and muscles is absolutely indispensable to their proper functioning.

6. Variations in the technical proficiency of piano pupils can, at times, be traced directly to variations in the respective circulatory systems. A correction of these circulatory defects will then correct these technical defects.

PART II

GENERAL ASPECTS OF PHYSIOLOGICAL MOVEMENT

CHAPTER VI

Geometrics of Physiological Movement

A study of the various joints at which movement takes place in piano-playing, will enable us to tell what type of movement is possible when the movement is restricted to a single joint. And conversely, given the path of the movement, we can learn whether or not it is the resultant of motion in one joint or in several joints.

Rotation in the shoulder-socket will use the humerus as a radius. The elbow will describe an ellipse or a circle. Such a motion is used in winding a windlass. In this type of movement in which joint-motion is restricted to the shoulder-socket, the elbow cannot describe a straight line. With the humerus it describes a cone of

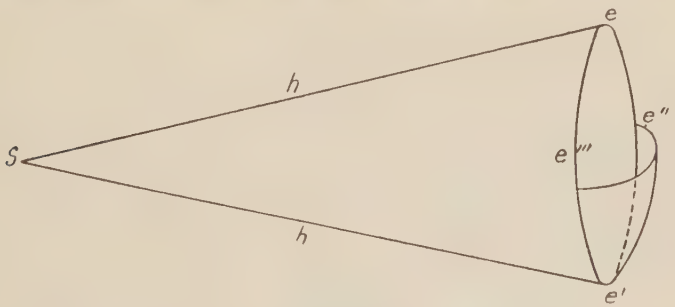

Fig. 20.

movement the pitch of which varies considerably, and the base of which is a spherical surface. In fact, the elbow cannot, in any case move in a straight line, since the humerus acts as a moving radius of fixed length. As a result the elbow must describe paths along the surface of the sphere generated by the multiplanar movements of the humerus.

By restricting the movement to one plane, the humerus as a whole may describe a segment of this plane. The elbow will describe one of an unlimited number of arcs across the base of the cone of Fig. 20. The direction of this arc in relation to its plane may be a straight line, but the movement of the elbow itself must be an arc of a sphere of which the humerus is the radius. So long as the shoulder is stationary the elbow cannot move in a straight line. Its

motions are all necessarily curvilinear, but may take place in any direction along the spherical surface generated by the cone of movement shown in Fig. 20.

When the humerus itself rotates around its longitudinal axis, the path described by any point fixed to the humerus and not in the axis of rotation will be the arc of a circle the radius of which is the perpendicular distance of the point from the axis of rotation. Straight-line movement from simple rotation cannot occur. Thus, in spite of the wide range of movements possible through the ball and socket joint at the shoulder, all movements of distal parts are curvilinear; the joint does not permit rectilinear movement.

Movement around the elbow-joint takes place in the arc of a circle the shortest radius of which is the length of the fore-arm. With the hand extended the radius is increased by the length of the hand. The movement, for the reasons given in the shoulder and elbow-movements, is curvilinear; rectilinear movement again is impossible.

Movement around the radio-ulnar articulation is a rotary motion of the fore-arm, approximately equivalent to the humerus rotation in the upper arm. Points not in the axis of rotation will, therefore, describe arcs of circles and not straight lines.

The wrist-joint permits rotation in two fundamental planes, the one generated by flexion and extension at the wrist, the other by abduction and adduction. In both cases the movements of distal points are arcs of circles. With flexed fingers the length of the radius is the length of the hand from wrist to hand-knuckle, with extended fingers, it is from wrist to finger-tip.

The finger-joints, likewise, generate motion in arcs of circles the radii of which are the lengths of the various phalanges. As simple hinge-joints they cannot generate rectilinear motion. Illustrations of these examples of curvilinear movement are given later in the analysis of vertical and horizontal movements, and in the various types of finger-stroke. See also the arcs of Figs. 9 to 14 and Fig. 20.

From these observations we may formulate three principles which have practical bearings upon problems of piano technique.

(1) All movement generated by motion at a single joint is curvilinear.

(2) Any motion of a part of the arm in a straight line results from simultaneous movement at more than one joint.

(3) Simultaneous motion in two or more joints can generate both rectilinear and curvilinear movement.

Thus, given a straight-line movement, we know that it is caused

by the participation of several joints ; but, given a curvilinear movement, we cannot, from this condition alone, know whether it has been generated by motion at a single joint or at several joints. This must be determined by a study of the skeletal parts involved in the movement, their spatial displacements and the degree of curvature in the movement.

But motion at a joint demands muscular coördination. Movements in straight lines therefore, since they involve the coördination of motion at several joints, are physiologically more complex than movements in the arc of a circle caused by one-joint. A straight descent of the finger-tip in a finger-stroke is mechanically more complex than the curved stroke resulting from a fully extended, flat finger. The former involves motion at each of the three finger-joints ; the latter motion in only the hand-knuckle. The vertical lifting of the arm over the keyboard ; its reverse : a chord-attack ; the horizontal transfer of the hand along any part of the straight-line keyboard ; in short any movement in a straight line, means that several joints are participating in generating this movement.

Isolation.

In this geometric relationship we find the greatest proof of the fallacy of " fixation " characterizing early piano pedagogy. The more we attempt to restrict motion to one joint the more does the motion become curvilinear. The building of the keyboard in a straight line is opposed to curvilinear movement as here understood. This condition has been responsible for building piano-keyboards that curve somewhat around the player, which, however, have never become generally used. They use the shoulder position as the centre of their arcs, attempting thereby to eliminate the trunk movements needed for shoulder movement.

From a purely geometric standpoint any movement of piano technique, excepting one form of the simplest finger-stroke, and an elbow extension with absolutely vertical upper arm involves motion at more than one joint. When we transfer our hand, for instance, from the region of middle C, an octave or two higher, the hand describes an arc, hence we may infer movement at one joint. But at the same time the line of action in the direction of ascent is a straight line parallel to the keyboard, and this necessarily involves movement at more than one joint. So it is with most other movements ; whereas they may be curvilinear in one or more planes they are, almost always, at the same time rectilinear in another plane, and are resultants of motion in more than one joint. The passing-under of the thumb in scale and arpeggio work ; the

vertical finger-descent ; all cantabile touches ; the lateral shift of the hand beyond the five-finger position ; crossing of hands ; simple arm-drop ; diatonic tremolo ; in fact any pianistic touch has in it some rectilinear motion and this can be produced only by movement in more than one joint. There is no exception to this relationship between straight-line movement and activity at more than one joint and, as a result, the isolation of movement to one joint is, in actual piano-playing, mechanically and physiologically impossible.

Curved versus Angular Movements.

But, although a rectilinear component will be found in practically all pianistic movements, the major part of the movement, at least the part with which we shall be chiefly concerned, and which will form the subject of our study, will remain curvilinear. The question whether pianistic movements are primarily angular or curvilinear may be answered after a study of the mechanical principles underlying the geometric phases of piano-playing.

The chief geometric characteristic of piano technique is change in the direction of motion. And physiologically this probably constitutes the biggest problem of technique. A change in direction may be abrupt or gradual. In the first case an angle will be formed ; in the second case, a curved line. The freedom of all curvilinear movements when compared to changes in the rectilinear movements is a fact so patent that its reality need scarcely be further shown. The operation of any machine illustrates it, and the readily perceptible awkwardness of angular bodily movement will prove it. This awkwardness results from interference with the law of mechanics according to which a body in motion remains in motion in unaltered direction unless acted upon by a force. The amount and abruptness of change in the path of a moving body depend upon the amount of force. Accordingly, sudden and marked changes in the direction of a movement involve the expenditure of much energy, and since the changes in direction do not, in such a case, contribute to the final aim of the movement, the latter becomes incoördinated. (See Mechanical Principles, 2 and 7.)

Repetition.

A second typical characteristic of pianistic movements is repetition, both absolute and relative : repetition without further displacement, and repetition of one part while the movement as a whole shifts along the keyboard. This complexity is at the bottom of all but the most elementary five-finger positions. The distal part of the arm, let us say, fingers or hand, is performing

a smaller and usually more rapid movement, while the proximal parts of the arm: fore-arm or upper arm, are moving in a wider range and usually at a slower rate. The activity at the various joints, therefore, is neither equal nor devoted to the same end. Instead, it usually consists of a slow, fairly continuous movement in the larger joints while the smaller joints are engaged in more rapid discontinuous movements.

Absolute repetition is found in such passages as the repeated octaves of Schubert's Erl-King, the accompaniment of Chopin's Berceuse, the left hand, second section of Chopin's F sharp major Impromptu, any sustained trill. In the analysis of such movements, I found a pronounced tendency on the part of the player to get away from the pure repetition in all rapid forms by shifting some other part of the arm than the part directly engaged in tone-production. This attempt, not always entirely successful, was so general that some physiological necessity must have prompted it. The necessity is probably muscular fatigue. In other words, rapid repetition tends to produce fatigue by over-shortening the period of chemical readjustment between movements. When the player begins to move a second part of the arm in addition to the part actually playing, he alters the direction-relationship between the parts. As a result he alters the muscular coördination somewhat, for the position of the muscles, their points of origin, extent, and their points of insertion are such that a skeletal part cannot be changed without affecting the mechanical pull of muscle, since the tendon is joined to the bone. A muscle acting in a certain way with the moved part in a certain position, will act in a different way with that part in a different position. And conversely, as a part is moved, the action of muscles often shifts from one group to another, some acting at a better mechanical advantage. This has been explained in detail in the analysis of muscular action, where numerous concrete illustrations have been given, and it will be further analysed in the study of the various touch-forms.

By adding a slow movement of larger muscles to the rapidly repeated movement, the player changes the movement from one of absolute repetition, to one of relative repetition. With this he eliminates absolute muscular repetition and consequently, in the case of rapid movements, reduces the danger of early fatigue. Let us take, as an example, rapidly repeated octaves. These are usually accompanied by a slow raising and lowering of the wrist. The muscular coördination producing the octave, with the wrist in a low position, is not exactly the same as that used when the wrist is in a high position. Nor is it entirely the same for any

change in wrist-position. (See p. 34, where the principle of range of movement is discussed.) For each stroke, therefore, a small increment of unused muscle is available, while at the same time, a similar increment of used muscle is permitted to recuperate. The physiological advantage of this procedure is obvious. At the same time we must not forget that it has also a decided psychological value, in substituting a higher unit at a slow repetition for the lower unit of rapid repetition.

Once again such a coördination is opposed to the doctrine of fixation or isolation. It has a disadvantage on the mechanical side because, at first, it increases the difficulty of dynamic control. This is shown in Fig. 96, which records various types of rapid tapping movements. The wave effects of the top record show the uncalled-for dynamic variations resulting from the admixture of the wrist movement and the hand-stroke. It takes considerable practice to eliminate the variations and yet retain the wrist-movement.

Speed of Practice.

In the element of fatigue we find one reason for slow practice in the early stages of instruction, especially in all repeated movements. In slow practice the time between strokes is sufficient to permit the muscular and chemical readjustment necessary as preparation for the following movement. There is no tetanic overlap. The elimination of muscular waste-products is complete before the next movement sets in. The quieter the hand, the more necessary is slow practice in repeated movements of the fingers, if the onset of fatigue is to be retarded. With children, especially, it is advisable to pause perceptibly between each repetition of finger or hand-stroke, so that the interference of one contraction with the next may be eliminated. Needless to say, slow practice has also a psychological value in its effect upon the direction of attention, but, at this point, we are concerned only with the physiological phase.

In rapid repetition, as figures in later chapters will show, the muscular coördination differs from that of slow repetition. The mechanical needs of the two movements are different and to meet these efficiently, the muscular adjustments must differ. Fatigue and fixation will be shown to be necessary correlates of rapidly repeated movements, and therefore, if postponement of fatigue and relaxation be the pedagogic problem, the reduction of the speed of repetition is a physiological necessity, to say nothing of the muscular tenseness which accompanies the feeling of hurry or anxiety as a modification of the biological fear reflex.

Direction of Movement.

Moreover, the direction of a movement is not in itself an adequate indication of the location of the contracting and relaxing muscles. The extension of the fore-arm is normally the work of the triceps. But if the extension takes place in a vertical plane, gravity will suffice to extend the elbow, without any contraction of the elbow extensors. And if the extension take place slowly, in such a position, the actual flexors remain contracted in order to counteract the accelerating effect of gravity. This has led some investigators into wrong conclusions as to the simultaneous contraction of antagonistic muscles. The contraction of the elbow flexors during a movement of elbow extension is not a sign that they are acting as initiators of the movement, but as inhibitors. And, for the same reason simultaneous contraction of antagonists need not mean incoördinated movement. Only when the contraction results in a hyper-tension, exceeding the demands of the actual resistance being overcome, does incoördination begin. We cannot, therefore, tell from the appearance of a movement what muscles are contracting, a fact which we shall meet again and again in analysing touch-forms.

In the best coördinated movement there is a considerable loss of energy, if the output is measured solely by the demands of the actual tonal values produced. In any keyboard movement, the greater part of the energy is consumed in shifting the parts into position for the final tone-production, and the amount of energy required for this is often a ridiculously small part of the energy used in the total movement. Yet, in spite of this apparently wasted work, the movement remains coördinated because the spatial displacement is absolutely essential to the desired tone-production. When the left arm is transferred slowly from a low bass region across the right hand to reach, let us say, a high treble key, played softly, practically the whole energy is used in transferring the arm, but a minute part being required for the actual tone-production. Yet the preliminary transfer is necessary in order to reach the key. The movement thus remains coördinated.

CHAPTER VII

Action and Reaction

We shall have occasion to study in detail the effect of finger-impact upon the joints of the arm in the analysis of coörd nated movement. In this effect is found the operation of a basic mechanical principle, the importance of which justifies some additional remarks. This principle of action and reaction, briefly stated, is that the forces acting on any point at rest are equal and opposite. When the finger-descent is brought to a stop by key-resistance the upward acting force of this balances the downward force of the finger. In a finger-stroke the descent of the finger was caused by a decrease in the angle which the finger makes with the hand, and this decrease, in turn, resulted from a contraction of the flexor muscles. When the descent of the finger-tip is suddenly arrested by the piano-key, the effect of the muscular contraction is still to decrease the angle referred to. Since the finger-tip cannot descend further, the only remaining way in which the angle can be reduced is by raising the hand-knuckle. The finger-tip thus becomes the fulcrum and the hand-knuckle the moving part; whereas, before the finger-tip reached the key the hand-knuckle was the fulcrum and the finger-tip the moving part. This interchange of mechanical points is an important characteristic of physiological movement. It is best observed in gross movement, as seen in gymnasia. When the overhead pulleys are pulled down, the shoulders act as fulcra, the biceps contract, the elbows are flexed, and the hands are drawn down toward the shoulders. In "chinning" a horizontal bar, the same muscles contract, but here the hands are the fulcra and the contraction of the biceps (plus, of course, accessory muscles) lifts the entire body until again the shoulders are brought close to the hands. This dual effect may be present in any other contraction, and, as a result, the same muscular contraction may produce different movements. If the two finger-joints are flexed, the finger-tip will approach the palm of the hand; but if a resistance be introduced against this flexion, thus making movement at the finger-tip impossible, the same contraction of the muscles will bring the finger-tip close to the palm by pulling the hand, and fore-arm and upper arm forward.

For the same reason, if the hand-arch be held firm, the impact of the finger-tip upon the key will result in an upward jerk at the wrist (the nearest relaxed joint). And the force manifested at this point will be equal and opposite to the force at the descending finger-tip. Even in a very light touch some of this reaction will be present. It cannot be eliminated. True, we can inhibit the motion by a preceding excessive contraction of the necessary muscles, but such contraction is highly incoördinated, since it usually exceeds the amount needed for tone-production.

On the other hand, the attempt to eliminate this reaction and thus to permit the finger-tip to exert its full force upon the key, is responsible for the fixation of joints to which frequent reference has already been made. If the hand-knuckle, for example, be very relaxed, the reaction will manifest itself as soon as the key is touched by the finger. But tone is not produced until the key has been almost completely depressed (the point of hammer-escapement). Therefore it is necessary, for the proper force-effect, to keep the hand-knuckle fixed as a fulcrum, at least until this point is reached. In a relaxed joint a part of the force which is acting upon the key is spent in moving the relaxed joint itself, hence must be lost for work at the finger-tip. It is for this reason that relaxed tone-production, however produced, is normally weaker than rigid tone-production.

Isolation.

The principle of action and reaction illustrates once more the impossibility of muscular or mechanical isolation in the physiological mechanism of man. External observation of bodily movements—upon which apparently most authors, teachers, and players base their deductions—is hopelessly inadequate in an analysis of the muscular activity responsible for the movement. For lack of motion certainly need not mean lack of force-action. The motionless state may result, it usually does result, from multiplicity of forces the total effect of which is equal and opposite. It is the familiar principle of the parallelopiped of forces. As a matter of fact, lack of motion frequently results from the necessary fixation of some point as a fulcrum. The muscle, for example, pulling the index finger toward the thumb is joined to a bone which carries also the connection of the thumb adductor. Accordingly, when it is desired to abduct the second finger toward the thumb, the position of the latter must be fixed to act as fulcrum. Consequently, the extensors of the thumb, which have nothing directly to do with the index finger, are contracted. Without their action the thumb

would move toward the second finger. Only one finger moves, but the necessary muscular coördination is not restricted to that finger. A similar situation is found in the abduction of any other finger, as well as in the grosser movements of the arm, some of which will be mentioned in this connection in the chapter on Coördination.

Moreover, when, with a sufficiently sensitive apparatus we record the positions of the various joints or parts of the arm during a movement, we find that what frequently appears a motionless state is, in reality, a minute movement, too small or too rapid to be readily detected by the eye. Fig. 21 shows this very nicely. The method of direct lever recording was used, one aluminum lever being attached closely behind the second finger-joint (first interphalangeal) of the index finger, while the other lever was attached between the hand-knuckles of the third and fourth fingers. This position

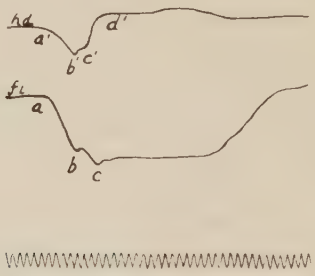

FIG. 21.

The time-lines in this and in following figures were made with a 50 d.v. fork.

precluded any motion in the hand-knuckle of the index finger from affecting the record. In order to detect very small movements in the hand-knuckle, the lever was so adjusted that these appeared on the record magnified three times.

Reading from left to right we find both finger and hand stationary. The first part of finger descent, from a to b is accompanied by a similar descent in the hand itself (a^1 to b^1), which indicates that the player making this record used some fore-arm or wrist movement. When the finger reaches the key-surface, shown at b, the hand-knuckle is affected, as the break in the line at b^1 indicates. The retardation of finger-descent (b to c) resulting from the resistance of the key, is directly reflected in the ascent of the hand-knuckle (b^1 to c^1). When the key is fully depressed (c) the effect upon the hand-knuckle is naturally more marked, and, accordingly, we find

a conspicuous rise in this part (from c^1 to d^1). The significant point is that even the slight resistance introduced by the piano-key is not without some effect upon the hand-knuckle. Without the magnification this (b^1 to c^1) would have been scarcely noticeable. But to infer its absence would be to misconstrue entirely the underlying mechanical principle. The marked break from c^1 to d^1 is a typical illustration of the principle of action and reaction.

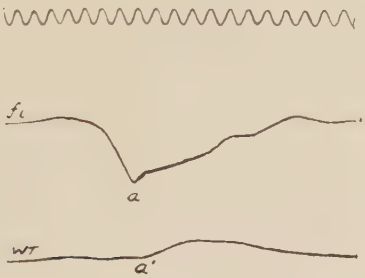

Fig. 22.

The reaction of finger-key-bed impact upon the wrist is seen in Fig. 22. A non-percussive touch was used in this instance, hence there is no retardation in the descent of the finger until the key is fully depressed. This point is marked *a*. At that moment the line recording wrist movement rises (the lever in this record was

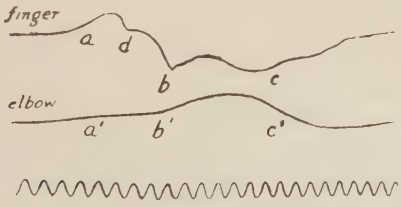

Fig. 23.

attached immediately behind the wrist), and as the finger subsequently rises, the wrist, in reaction, falls again to its original level.

But the reaction carries over further than the wrist; it also affects the elbow. In Fig. 23 this reaction is shown by the rise at b^1 in the line recording elbow movement as the key-bed is reached (*b* in the finger-line). The rise at a^1 is too slight, and occurs too

soon to be a reaction to the impact of the finger against the undepressed key (shown at point *d*). It is a sympathetic rise to the initial finger-lift between *a* and *d*. This rise is in no way a contradiction of the principle of reaction with which we are here concerned. Because at the point *a* the finger has not met any resistance, and is travelling freely through the air, hence there cannot be impact-reaction at another joint. This fact is conclusively shown by recording the movements of finger and hand when the former is moved without meeting any resistance. The result is given in Fig. 24. I selected hand-movement because, if there were any reaction from the finger-movement, this would show most clearly in the movement of the hand-knuckle, the nearest part.

The line tracing the hand-movement (the upper line in the figure) remains straight, although the instrument had been set to magnify any deflection five times. The finger-line shows the path for two finger ascents and two descents.

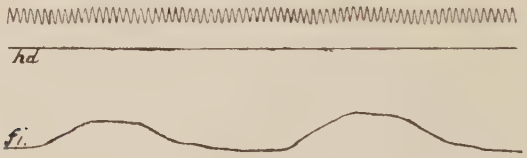

Fig. 24.

External Resistance.

This brings to light the necessity for carefully distinguishing between a movement made free from external resistance and the similar movement made against external resistance. The distinction grows in importance in the psychological phases of piano technique. In all percussive touches the attainment of the desired tonal effect can be shown to depend primarily upon the proper image of that result before the movement is initiated. To practice the movement without the tonal result is, so far as its direct effect upon the application of the movement is concerned, psychologically unsound. The mechanical, silent, keyboard devices lose in value on this account.

This does not mean, however, that practice of movement without resistance is of no pedagogical value. Quite the contrary. Such practice is the best and surest way of teaching the misnamed, but technically helpful, isolation of movement. The records given in

this chapter show that with resistance there is a reaction at other joints. The inhibition of this reaction demands a spread of tension over these joints and hence directly opposes the aim of the movement, which is isolation. By work ng from the zero point of intensity to the louder degrees, we proceed from minimal to maximal muscular spread. On the other hand, to demand of a pupil a tone-production of even moderate loudness with the finger, while the other joints of the hand and arm are fully relaxed, is to demand the impossible. No one ever has played that way, and no one ever will.

Action and reaction are present also, and operate the same way when the key-attack is so short that muscular adjustments cannot be made during key-depression. When, for example, a chord is played loudly and quickly, the hand is firmly fixed as the arm descends and before the key is struck. The reaction, I might say, is present before the action causing it. This contradiction is only apparent. What actually happens is that the player images the key-resistance, and hence prepares the spread of muscular contraction, the necessary fixation of the joints, before the key is reached. Through experience and talent this image can function very accurately, and upon its accuracy depends the question of whether or not the player will get the desired tonal result. Insufficient fixation or an excess thereof, is to be classed as incoördinated movement, because, from the standpoint of interaction, a coördinated movement is one in which action and reaction are equal and opposite. It is the physiological application of the physical principle of the parallelopiped of forces, which defines a point at rest as acted upon by forces whose directions are opposite and whose magnitudes are equal.

Lateral Finger-movement.

When finger-movement is mentioned, we normally think of it as taking place in a vertical plane, the typical down and up strokes of the finger. Seldom is any thought given to the effect of a finger stroke on the lateral movement of adjoining fingers. And yet it is this lateral action and reaction that gives us the approach to a study of the muscular adjustment needed in the hand for a single finger-stroke.

The location of the muscles in the palm of the hand, and the lines of pull of their tendonous attachments, make necessary a direct interaction of adjoining fingers. A diagrammatic illustration of this arrangement is given in Fig. 26.

A, A^1 represents the meta-carpal and first phalanx of the index finger, left-hand, seen from the palmar side. This makes *e* the hand-knuckle articulation. B, B^1 show a similar part of the third finger; *c* and *d* the location of the muscles and their coherence. A pull on *a* will thus affect *b*, and when *a* contracts to move A^1, *b* is affected and tends to move B toward A. This effect is always present in a free finger-stroke of an untrained hand. Fig. 27 gives

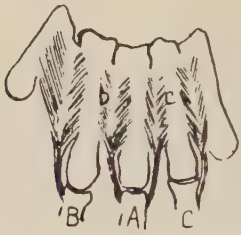

Fig. 25.

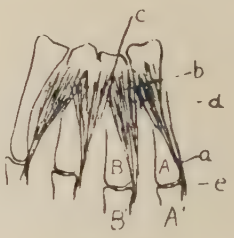

Fig. 26.

two illustrations of it. A stroke of the third-finger was used and was recorded on the kymograph by means of a pneumatic tambour. Deflections in this line are, therefore, not finger-movements, but merely record the time of finger-key impact. The line for the second finger, however, recorded the actual finger-movement, laterally, and any deflection toward the other line means that the

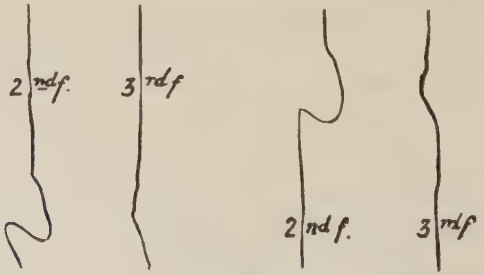

Fig. 27.

second finger actually moved toward the third or the playing finger. During the third-finger-stroke, the second finger was held free, not touching any fixed object. The reaction is seen clearly in each case.

Wherever the third finger plays, as a result of the muscular contraction, the second finger is pulled toward it because the deflections in the two lines coincide. This coördination may be readily observed in the playing of any untrained pupil, by standing directly

Fig. 28. Method for third-finger control during stroke of second finger.

[*To face p.* 88

behind him and watching the lateral finger-shifts that will accompany any slow, fairly loud diatonic passage. It is a familiar pedagogic problem in violin and violoncello also.

It follows that when this reaction is eliminated, that is to say when the finger-stroke is isolated, the muscular adjustment is more complex, covers a wider field than in the non-isolated movement just described. For, in order to neutralize the deflection of the unused (index) toward the used (third) finger, the muscle on the other side of the index finger (thumb side), must be contracted. And so on, in various degrees, throughout the hand. Thus what is apparently a simple finger-stroke is a very complex adjustment of hand muscles, made necessary by the principle of coördination, in accordance with which other muscles than those actually moving must operate to fix the necessary fulcra.

A similar condition exists among the dorsal interossei. These are bipenniform muscles arising from two heads on adjacent sides of the carpal bones. The relationship is shown diagrammatically in Fig. 25.

Accordingly, a marked downward finger-stroke, let us say, of finger A, would tend to pull both *b* and *c* toward it, and would in turn move B and C in the direction of A. Such mechanical interaction, when not desired, is counteracted by the simultaneous contraction of muscles opposed to this movement.

Knowing this, the teacher can proceed to work against the original reaction, which is pianistically undesirable. Since the proper coördination demands contraction of the muscle on the far side of the non-playing (passive) finger, so that this finger will remain away from the playing finger, resistance may be introduced against the passive finger to insure the muscular contraction, and this resistance should be maintained while the second finger plays. The muscular uselessness of holding the pupil's finger in the desired position is discussed in the chapter on Activity and Passivity. A method which I have found useful is illustrated in Fig. 28. Here the pencil is pressing against the third finger, the pupil pressing against the pencil, thus contracting the desired muscle, as the index finger, shown in action, continues to move.

This lateral finger-movement is an interesting example of the principle of action and reaction. It serves to show that in all physiological movement, similar coördinations directly opposed to isolation take place, because the mechanics of the movement do not change. A part of the body is not necessarily in a state of relaxation or passivity because it is motionless, in fact, unless it is resting upon some outside body, or is in another form of stable equilibrium, it is never relaxed.

CHAPTER VIII

Activity and Passivity

Bodily movement may be caused in two ways: by voluntary or involuntary contraction of muscles through neural stimuli, or by the action of some outside force upon the part to be moved. If I lift my arm with the idea of reaching for something, the movement is the result of muscular contraction. This I shall call an active movement. If, on the other hand, another person takes my arm and lifts it into the same position, the movement is the result of the action of the force supplied by the other person, and, so far as I am concerned, the movement is passive, since I am not doing any work. The movement made by the other person in order to bring my arm into the desired position is an active movement. If conditions were reversed and I should be lifting his arm, I should be making the active movement and he would be making the passive movement. The difference in the muscular coördinations between these two types of movement has a most important bearing upon problems of piano pedagogy. For here the teacher very frequently moves the pupil's arm, hand, or fingers through the desired movement. It is advisable to learn whether in so doing the actual muscular reaction of the pupil is the same as that made when the pupil performs the movement unassisted, or whether there are differences, and, if so, what these differences are.

There are several ways of learning this. Following the plan of procedure adopted in other chapters I shall first treat the theoretical phases and then correlate these conclusions with actual records obtained of the muscular contraction in both types of movement.

In the chapter on coördination we shall learn that economy of effort—we may call it the law of least effort—is the fundamental requirement of a coördinated movement. Nature would defeat its own purpose, therefore, if an organism making a passive movement expended the same amount of energy as when the same movement is made actively. If, to return to the example of arm-lift described in a preceding paragraph, it takes ten units of force for me to lift my arm into the desired position, it will take at least ten units (and necessarily more) for someone else to lift my arm.

But any part of this ten that I expend while my arm is being lifted is superfluous energy, since the outside agency is capable of doing the work. Accordingly, we may expect to find at least less contraction in passive than in active movement.

And since any participation is unnecessary, no contraction whatever would be the most economical procedure and would most closely follow the law of least effort, since any contraction, no matter how slight, involves some effort.

The problem is somewhat complicated by the fact that the spatial relationships in both types of movement remain the same. The points of muscular origin and insertion, therefore, are alike, and yet the condition of the intervening muscle differs. Much confusion on this question has arisen through the popular comparison of a muscle to an elastic band. The simile holds only to a limited extent. If the property of elasticity, by virtue of which a body returns to its original shape when the force responsible for its preceding alteration ceases to act, were inherent in the muscle, any stretching of a muscle would be accompanied by a constantly increasing resistance, equal exactly to the force responsible for the stretching. This is the principle upon which all spring balances, sling-shots, and similar devices are based. It is entirely opposed to the principle of relaxation which is discussed in the chapter on Properties of Muscles, and also to that of coördination, discussed in Chapter IX.

The same opposition is found when the distance between the points of origin and insertion is lessened. If elasticity were an inherent muscular property, the muscle would contract directly with diminution of this distance, whether the movement be made actively or passively. But muscular contraction involves work, and work is always the result of an expenditure of energy. Hence we should have the muscle, in passive movement, doing the same amount of work as in active movement, a condition flatly opposed to the law of least effort.

The difference between elasticity and contractility, lies in the fact that the latter, for its operation, depends upon the presence of a neural stimulus. Without this (or an artificially supplied stimulus) a muscle does not contract. The degree of contractility does not depend upon the spatial relationship between the points of origin and of insertion, it depends upon the intensity of the neural stimulus. A muscle may, therefore, have similar shapes yet be in opposite stages of contractility. If the arm be sufficiently bent at the elbow by an outside force, the pressure of fore-arm against upper arm will cause a swelling in the region of the biceps muscle.

A similar swelling occurs when the biceps is contracted voluntarily, but the physiological states of the muscle in the two cases are widely different. In one case no muscular activity is going on, no chemical changes are taking place ; in the other work is actually being done with chemical changes in the production and elimination of heat and fatigue products.

These facts are substantiated by records of the muscular contraction actually taking place in both types of movement. The method of direct observation, which does not involve the use of any apparatus, serves to illustrate certain features of the differences we are considering. The biceps contraction already mentioned is a case in point. With the back of the hand and the fore-arm resting upon a table, place the fingers firmly over the biceps muscle. This, as I have already pointed out, is the muscle meant when the enthusiastic youngster asks his companions to " feel my muscle ", and proceeds to flex the elbow and supinate the fore-arm. The muscle with the fore-arm resting upon the table will be found in a relaxed condition. Now proceed to lift the fore-arm slowly. The muscle will contract, and a part of this contraction can be felt before the hand or arm leaves the surface of the table ; in other words, before movement of the external parts has taken place. The points of origin and insertion of the muscle could not, therefore, have been altered and thus is shown the independence of the degree of muscular contraction from the spatial position of the parts to be moved. A weight placed in the palm of the hand will intensify this reaction. A similar, more marked result, occurs when the hand is pushed against an immovable object, for example, pressed forcibly upward against a table or desk. The biceps will contract violently, yet the position of shoulder and fore-arm, the places of origin and insertion respectively, have not been altered. The contraction depends upon the force acting against the muscle, not upon the position of the parts.

A finer, and perhaps, more convincing proof is found when we record by graphic means, the contraction of a muscle or its non-extensible tendon, when the muscle itself is moving the part, and when the same part is being moved by an outside agency. The following figures are records of the contraction of the third finger tendon of the extensor communis digitorum, the muscle responsible for all finger-lift in the hand-knuckle, one of the most important pianistic movements. The method of recording is shown in Fig. 29. A long aluminium lever, with an adjustable setting is so placed that its edge rests upon the tendon, the contraction of which is to be recorded.

Fig. 29. Instrument for recording contractions of finger-extensors.

Fig. 31. Difference in muscular contraction between passive (*a*) and active (*b*) finger-lift.

[*To face p.* 92

Its position in any other plane of movement is fixed by its own axis and the two points resting upon the hand near the tendon. Any contraction of the tendon will then lift the lever, and by making this sufficiently long, and placing the fulcrum sufficiently close to the tendon, any degree of magnification may be secured, thus recording even extremely slight degrees of contraction. These are then transferred upon the smoked surface of a revolving drum, passing beneath the free end of the lever.

The results are seen in Fig. 30. In the upper line, the finger was lifted by another person, in the lower, the subject lifted his own finger by voluntary muscular contraction. An ascent in the line indicates a pull on the tendon resulting from the contraction of the muscle, the height of the ascent furnishing a fair index of the degree of contraction. In the passive movements there is complete absence of contraction. In the active movements the marked contraction for each of three successive finger-lifts is clearly shown. The number,

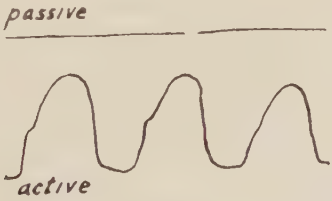

Fig. 30.

extent, and speed of movement were exactly the same for both experiments.

In Fig. 31, this difference is photographically shown. One picture illustrates the third finger being lifted by an outside agency, and the absence of any ridge across the back of the hand, proves the absence of the muscular contraction; whereas in the other picture showing voluntary lift of the same finger, the well-defined ridge across the back of the hand, representing the tension of the tendon leading to the muscle, is clearly visible.

The rubber-band simile is thus seen to be inadequate in the study of muscular reaction. The muscle does not contract when the distance between the skeletal and muscular attachments merely decreases, but only if the decrease demands overcoming external resistance. Slack is taken up only when opposed by muscular activity in the antagonists. Then the "give and take" is very nicely adjusted, leading to very fine degrees of coördinated movement. When the movement is caused by external force alone,

the purpose of any " balanced " reaction obviously vanishes, since the organism no longer has anything to do with the aim of the movement.

The same passive condition holds when external forces stop a physiological movement. If the arm be moved rapidly in a lateral direction—as for example, in a leap from middle C to C^3 on the key-board—it will normally be brought to a stop by appropriate contraction of the large chest-muscle (pectoralis major). If, on the other hand, a cushion be placed at the end of the movement, and the arm be thrown freely against it, letting the cushion do all the stopping, the need for muscular contraction vanishes, and the muscle takes no part in the movement. This is shown in Fig. 34, *a*, *b*, in the chapter on Coördination and Incoördination.

The muscles yielding in stretch to the increase in distance involved do so without any increase over their normal tonicity. And the muscles yielding to a decrease in distance likewise do so without an alteration of their normal tone. This leaves for consideration the muscular reaction when the distance relationships remain constant and the muscular contraction changes. What happens, for example, when the finger-tip meets a fixed obstacle—such as the fully depressed piano-key—yet the muscles controlling finger descent continue to contract? Do the antagonistic muscles continue to relax proportionately or do they cease when external movement ceases?

Since all such contraction is voluntary, and since the compensatory relaxation of the antagonistic muscle group is concomitant with this contraction, in the sense, of course, that it contributes to the coördination of the movement, we may expect the relaxation to parallel the contraction. When movement has stopped, therefore, but contraction continues, the other muscles will reach the state of hyper-relaxation. The tendon will become slack in proportion to the degree of excess contraction of the other muscles. If this results, let us say, in ten units of excess pressure on the key-bed, there will be ten units of " slack " (hyper-relaxation) in the antagonistic muscular group. The presence of this excess looseness is illustrated in the chapter on Coördination, p. 117, where the experiment of pushing the tendon to either side, to show the slack, is described. The relationship concerns the active and passive phases of movement only in so far as the excess relaxation bears a close mechanical analogy to the passive state of movement, although I do not feel that they are entirely the same. They both are forms of moderate incoördination, since, in order to become effective, the hyper-relaxed muscles must first take up the " slack " in the tendons.

Degrees of Activity and Passivity.

The active and passive conditions of movement do not necessarily exist in a mutually exclusive state. A movement may partake of the attributes of both. If I am lifting a heavy weight and a second person assists me, I am both actively and passively engaged in the movement; actively, to the extent that I myself am doing the work, passively, to the extent that the assistance offered relieves me of the necessity for doing it all. The degrees to which the two forms combine are unlimited, varying throughout the entire dynamic range of movement. The assistance which we receive may be almost nothing, when the movement will be almost entirely active. Or the assistance may be nearly complete, in which case the movement will be practically entirely passive.

The question remains, of course, as to how gravity, as an external force, affects the activity and passivity of movement. The arm, for example, unless supported by some external resistance or muscular contraction, will fall through the action of gravity, hence without the contraction of the arm-depressors. Is this, then, a passive movement? We shall be obliged to answer in the affirmative, because our definition of passivity was based upon absence of muscular contraction. When, however, such an arm-drop is controlled—and the uncontrolled drop, as I shall show later, plays no part in piano technique—we have at least a partially active movement. Moreover, since gravity is a constant, and a force actually determining the basic coördination of all physiological movements, we may safely exclude it as a determinant of the activity or passivity of a movement in the sense in which the variable external resistance introduced by some obstacle or second person acts as a determinant. This does not mean, however, that its influence on the various touch-forms is to be minimized. Quite the contrary, its action is certainly one of the important determinants, perhaps the most important, of the forms of movement used in all piano touches. In order to avoid confusion of terms, I shall discuss this action under the positive and negative aspects of the various touch-forms.

Movement-Phase.

Most movements in piano technique involve repetition. Moreover, most of them are reciprocal motions, movements in opposite directions. One direction produces tone, the other serves merely as the spatial preparation of the next tone-production. Finger-lift, for example, is in itself useless for tone-production; its use lies in the preparation which it gives to the next finger-descent,

the actual tone-producing stroke. Arm-lift is useful only because it enables us to follow it with an appropriate arm-descent. Finger-lift and arm-lift, therefore, may be considered the negative movements, finger-descent and arm-descent, the positive movements.

Keyboard Application.

These conditions all have a direct bearing on various problems of piano technique. A very usual method of procedure employed to teach a pupil new movements—be they of finger, hand, or arm—is to take the part to be moved and by appropriate force move it for the pupil through the desired range. The teacher supplies the force and makes the movement actively whereas the pupil makes it passively. As a result the muscles responsible for the movement do not contract and hence cannot either receive or send the proper stimulus to the brain-centres. Muscularly the pupil has learned nothing. At the most he has been given certain sensations of rotation at the joint at which movement takes place. In view of unfinished experiments I am not at present prepared to say to what extent these are a help later on in reproducing the movement, for this is primarily a psychological problem. But we may rest assured that muscularly the reaction is not that which is ultimately responsible for the movement.

As a matter of fact, if the correct muscular contraction be the pedagogic aim, just the opposite method of procedure is advisable. Instead of introducing a force acting in the desired direction of movement, we should introduce a resistance against this movement, or, what is the same thing, a force acting in an opposite direction to the desired movement. If finger-lift be the problem, press down upon the finger instead of helping to lift it; if finger-drop be the problem, press up against the descending finger. Then, and then only, will the correct muscles be contracted, because a muscular condition does not depend upon the position of the parts but upon the external resistance opposing the maintenance of the position. There can be no doubt of the physiological or mechanical advantage of this procedure, even if it is opposed to the usual pedagogic procedure. The value, if any, in aiding a movement by relieving the maker of the movement of a part of the work cannot rest in any physiological or mechanical phase. It violates absolutely a fundamental law of physiological mechanics. But this help should not be confused with a somewhat similar, very helpful, procedure in which a slight touch or pressure in the direction of the movement is supplied by the teacher. This acts merely as a suggestion following which the pupil makes the movement unaided.

For the same reason practice in tone-production without key or some substituted resistance is pedagogically unwise. The key-

resistance causes the muscular contraction—without the former, the latter is absent. And this brings us to an important point: the distinction between the appearance of a movement and its mechanical nature. The characteristic "playing in the air" or "on the surface of keys", typical of pupils in whom finger-action has been unduly stressed is the result of separating the visual aspect of the movement from the mechanical. The only logical use of finger-action is the production of an appropriate tone, and this production depends entirely upon speed of key-depression,[1] that is to say, upon appropriate overcoming of the key-resistance. We cannot judge the coördination from the appearance of a movement but solely from its mechanical nature.

These observations apply to any touch-form. The contraction of a muscle depends not upon *as*sistance but *re*sistance. Any external help given in a movement absolves the muscles from the necessity of doing that much work, and results in an incoördinated movement so far as its pianistic value is concerned. All exercises in which the muscular activity is accompanied by external assistance do not permit the proper coördination. Exercises for increasing the various stretches may help, if carefully done, by slightly increasing the extensibility of the tissues; but they do not develop the muscular coördination which, later on, is used to attain the stretch in actual playing.

The distinction between the positive and negative phases of movement is not merely academic. Instead, it is based upon a mechanical difference. A negative movement has no external resistance to overcome, the resistance of friction among the parts moved, being internal. A positive movement does overcome external resistance. In lifting the finger, its own weight (plus, of course, friction at the joints) is the only opposition to the movement, and the movement does no external work. In finger-descent, on the other hand, the aim of the movement is key-depression. It is necessary in all practice to keep this distinction in mind. If finger-lift be considered the positive element, the movement results in an excessive lift with the extensors straining against the fully extended tendons and ligaments. (An interesting illustration is given under Arm-Legato.) This represents so much wasted work. It does not lift the finger higher, hence cannot effect the following finger-descent favourably. Normally the pupil's attention should be directed toward the positive not the negative phase of the movement. This we shall have occasion to note repeatedly in discussing the various touch-forms.

[1] Ortmann, *Physical Basis of Piano Touch and Tone.*

The fundamental law of passivity, therefore, may be stated as a subsidiary of the law of least effort : whatever work is done by an outside agency in moving any part of the body, relieves the muscles normally responsible, and as a result, they relax, and the physiological nature of the movement changes, though its external appearance remains the same.

CHAPTER IX

Coördination and Incoördination

A movement is the displacement of a certain body through a certain space in a certain interval of time. Since in piano-playing random movements are not considered, we may add aim, as a fourth element of movement, to weight, distance, and time. A coördinated movement is a movement which fulfills the requirements of arm-weight, space, and time with a minimum waste of physiological energy. An incoördinated movement is a movement in which this minimum is not reached. Waste of psychological energy may be produced by incorrect weight, distance, or time, as a result of which the aim of the movement is either not fulfilled, or is fulfilled by an expenditure of energy greater than that necessary for particular movement. Suppose a force of ten is required to move the arm through one octave in a half-second, producing a tone of given loudness. A force of less than ten with the other elements constant, will then not suffice to meet these requirements. The tone will be too soft, or the time of the hand-movement will exceed one-half second. A force of more than ten, no part of which is acting antagonistically to another part, will cause too loud a tone, or too great a leap, or too quick a movement. These excess effects may be counteracted by appropriate contraction of the antagonistic muscles. If, for example, the speed be sixteen units instead of twelve, a contraction of four in the antagonistic muscles will reduce the speed to the desired rate. But together there will be an expenditure of twenty units to produce work which twelve can do. So that, although the movement, to all outward appearances, will have been correctly executed, the adjustment is biologically wasteful, and the movement becomes incoördinated.

Relaxation and Coördination.

In piano-playing the mechanical aim of all movements is the production at the piano-key at the proper time and place of a force sufficient to produce the desired tonal intensity. However complicated the final results of artistic piano-playing may be, they are produced entirely by variations in time-duration, in direction or point of application, and in force. Suppose middle C

is to be played with a force of eight ounces. This force can be secured in many ways. I can drop my arm (the normal adult arm weighs from 6 to 15 lbs.) from a considerable height, letting gravity accelerate the movement and increase its force. This will be far in excess of what is needed. Accordingly, as the finger appoaches the key, I must inhibit the descent of the arm by contracting the forward abductors of the shoulder. If this inhibition be just the amount needed, the finger will reach the key with the desired force-effect of eight ounces. The movement as a whole, however, will have been incoördinated, since there would have been obvious waste of effort. The inhibition of descent will have been a coördinated movement since the goal was reached. If, in order to produce the same effect, I raise my arm for a part of the distance, sufficient, when it is dropped, just to produce the desired force-effect, the entire movement will be coördinated, because there are no excess movements either in force or in amplitude.

We are now in a position to understand the relationship between relaxation and coördination—by no means synonymous terms. A coördinated movement necessitates the presence of just that degree of muscular relaxation that will transmit the desired force to the desired point in the proper time. The degree of relaxation depends entirely upon the force required to produce the effect, more rigidity or less than necessary will produce an incoördinated movement. An incoördinated movement results from excess relaxation as well as excess contraction. Too much relaxation (as in locomotor ataxia) may produce a movement just as inefficient as that produced by too little relaxation, as in paralysis of a muscle-nerve.

Let us take the normal arm-hand position shown in Fig. 166 as an example. The weight of the arm is supposed to rest upon the keyboard through the finger-tips. If normal arm-weight be active, this will suffice not only to depress the keys upon which the fingers are placed but also to exert a considerable part of its weight upon the elbow and the wrist joints. If these joints were completely relaxed, no resistance would be offered to the vertical action of the arm-weight. As a result, the wrist would be forced down and forward until the hand rested against the wooden casing beneath the keyboard of the piano. Or, the upper arm would seek a vertical position and pull hand and fore-arm from the keys. Such an arm-position, as we shall see later, is useless for piano-playing. As a matter of fact, it is mechanically impossible to rest the entire weight of the arm on the keys. Some of this necessarily is supported at the shoulder. But even whatever is left, can be transmitted

to the finger-tips and through them to the keyboard, only when every joint between the shoulder and the finger-tips is held sufficiently rigid to support, without movement, whatever weight is to be so transmitted. The mechanics of this leverage system are discussed later in connection with the various types of pianistic touch. The proof thereof will be found in the chapter on Relaxation.

The shoulder, in such a case, is the only fully relaxed joint involved in the arm-rest position. All other joints are fixed beyond the resistance point, or, at least, up to the resistance point necessary to support the arm-weight. Since the aim of the movement is just this support of the arm, the movement is fully coördinated. Here, then, coördination and relaxation are actually opposed. When such joint-fixation exceeds the amount demanded by the force of finger-key impact we have an incoördinated movement. The " stiff wrist " of pupils is an example. This stiffness, however, is not without a physiological basis. High finger-lift is normally associated with contraction of those wrist muscles which lower the hand at the wrist ; down-stroke of the finger with the contraction of the muscles pulling back the hand at the wrist. A rapid alternation of finger-lift and finger-drop, accordingly, sets up simultaneous contraction of the antagonistic muscle groups at the wrist and causes stiffness. Slow finger-stroke against little or no resistance will eliminate the stiffness. This association between finger and wrist muscles, needless to say, is a mechanical necessity if the force is to act at the finger-tip. Otherwise, instead of moving the key, the wrist will move in the opposite direction.

Whenever the tendon of a muscle passes over more than one joint, relative fixation of all joints over which it passes is necessary to permit the force to act at the desired point. And since practically all tendons pass over two joints, some even over four, isolation and relaxation, in their strict sense, do not exist in the physiological organism as applied in piano-playing.

If, instead of a fixed position, we consider the process during the movement itself, we find similar conditions. If the arm be permitted to drop freely its speed will vary with the time, since gravity is a constant. Any speed slower or faster than this shows muscular control ; if faster, it shows contraction of the muscles pulling downward on the arm, if slower, it shows contraction of the muscles pulling upward. Since the centre of gravity of the arm is just below the elbow, a perfectly relaxed arm would descend with this point in a straight line. As the key-level is reached the hand would be bent back (since the various finger-joints and the

wrist-joint are supposed to be fully relaxed) and the arm would assume the position described in the preceding paragraphs, so that here again complete relaxation would defeat the purpose of the movement.

Variations in Coördination.

A preliminary survey of coördinated movements discloses, among other things, that muscular coördination changes with a change in the speed, range, and force of a movement. The muscular action of a rapid movement differs from that of the same movement of extent and force, made slowly ; the action of a forceful movement differs from that of a weak movement of the same range.

Speed Effects.

We speak correctly of coördinated and incoördinated movements because the same movement, so far as its external characteristics are concerned, may be made in many, physiologically various, ways. And changes in the speed of a movement, though its range and direction remain unchanged, likewise involve variations in muscular response. These variations are not necessarily incoördinated movements. Quite the contrary ; they usually indicate a high degree of coördination.

In considering the effect of speed upon the muscular action in a movement, the most natural inference is that increase in the speed of the movement is paralleled by a like increase in the speed of muscular reaction, extending throughout the range of movement. This, however, is not true. The type of muscular reaction changes radically with variations in the speed of movement ; it must do so for mechanical reasons. Taking the arm for an example, we have its weight as a constant and, since we are dealing here with a given movement, the range and the general direction as other constants. The variable is speed. If the muscle contracts more quickly (forcibly) it carries the arm through a given distance in less time. The arm thus attains a greater momentum. A continuation of this increase in muscular contraction will naturally reach its maximum at the end of the movement. In order to bring the movement to an end, therefore, a maximal impact with some obstacle must take place, or an instantaneous relaxation of the contracted muscles and powerful contraction of the antagonistic muscles in order to overcome the momentum of the moving arm in that instant. Mechanically this interaction of forces, in the case of muscular contraction, may be compared to the sudden application of the air-brakes on a rapidly moving rail-road train ; or in the case of impact,

to the striking together of two obstacles. The shock—the result of maximal force-transformation in minimal time—not only places a considerable strain on most parts of the mechanism but also lessens the control of the act on considerably. This undesirable effect of shock on muscular movement, is discussed repeatedly later on, in connection with the analysis of various pianistic movement forms.

In a slow movement the same arm generates less force, this being the product of the mass and the acceleration. The momentum being less, the necessary inhibition can readily occur very close to the end of the movement. If we assume, in order to make this difference clearer, that one-fifth of a second is required to bring the arm to rest, a slowly moving arm may be practically at the end of its movement before the muscles need contract to bring it to a full stop. A rapidly moving arm on the other hand covers much more space in a fifth of a second. Hence the muscles will have to contract earlier in the course of the movement or more powerfully nearer the end. This is necessary because the rapidly moving arm has a greater momentum, which requires a greater force to overcome it.

In the second place it takes time and force to set a body at rest into motion. In a slow movement this time is not a conspicuous determinant. But in a rapid movement, a quick " get-away " is obviously essential. That is to say, it is necessary to set the arm into motion as quickly as possible. This demands more force, and accordingly a greater initial muscular contraction. The arm at the beginning of its movement, is thus given considerable speed. Thereupon the muscles are somewhat relaxed, while the arm, through its initial momentum, continues on its path as a relatively free body. Since the initial speed may be made sufficiently great to meet the aim of the movement further increase during the movement is not necessary.

A force may be measured by the work it does, which in turn is shown in the time and distance through which an object is moved. Assuming that inertia, atmospheric and joint resistances, and gravity are constants ; and that a force of 1 will move the arm through 1 inch in 1 second ; then a force of 6 will move the arm through 6 inches in 1 second. At the end of the first second the arm has a velocity of 6 inches per second. If, thereupon, the force ceases to act, the arm will continue at this rate (ignoring the factors of inertia and resistance mentioned). At the end of 5 seconds, therefore, the arm will have covered a distance of 30 inches. Now suppose that a force of 1 acts during the first

second. This will move the arm through 1 inch (5 inches less than the distance before). Then a force of 3·5 will move it 3·5 inches during the second second, giving a total displacement of 4·5 inches in two seconds. At a similar rate of force-increase the arm will move 6 inches during the third second (or a total of 10·5 inches); 8·5 in the fourth; 11·0 in the fifth. Totalling these distances gives a displacement equal to the other, 30 inches. These relationships may be diagrammatically illustrated as in Fig. 32.

The straight line shows the arm-displacements when the maximum velocity is attained at the beginning and maintained throughout the stroke. The upper, curved line shows the displacements with a slow beginning and increase of velocity during the movement. The dark points show the positions of the moving body at each

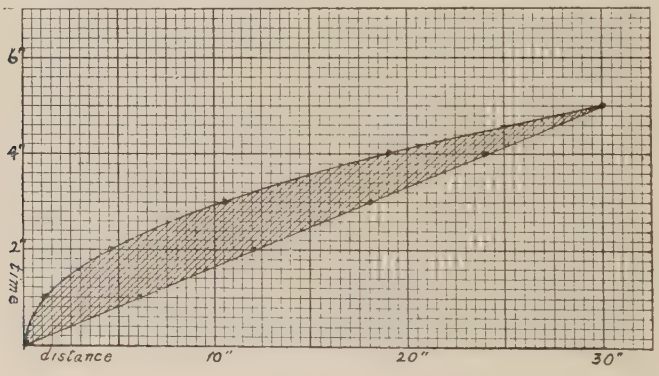

Fig. 32.

second. Finally, the shaded portion may serve to indicate the excess energy required in giving to the arm its necessary final velocity after a slow beginning. The figure is purely diagrammatic. Records of actual movements are given later.

Thus, by using a maximum at the beginning of the movement, a force of six suffices. By beginning slowly and adding force throughout the movement, a final maximum force of eleven is needed, almost double the other. Various rates of increase, of course, are possible, but, regardless of the actual rate, any increase during the movement represents excess energy, which, as we have seen, is characteristic of incoördinated, not coördinated movements.

But it does not follow that this advantage applies to slow movements. The slower the movement the greater is the effect of the constant factors, heretofore ignored: atmospheric and joint-

resistances, gravity, and inertia. Take the action of gravity, for instance, in a horizontal movement. Assume its numerical value to be 2. Its direction of pull, in a horizontal movement, will be at right angles to the line of arm-movement, and will tend to pull the arm down. If the movement lasts two seconds, gravity will exert a total force-effect of 2×2 or 4, the product of the numerical value of the force and the time through which it acts. If the movement lasts 10 seconds gravity will exert a total force of 10×2 or 20; five times as great as before. Again, assume the joint-resistance through the 30 inches of movement to be 60, the mass of the arm 10, and its acceleration 6. Since force equals the product of the mass and the acceleration, the force of the moving arm will be 10×6 or 60, sufficient to overcome the joint-resistance. Now suppose the speed of the same arm to be 2 instead of 6. Its force will then be 10×2 or 20, only one-third of the force necessary to overcome the resistance. At the same time gravity acts for a longer period and its force is correspondingly increased. Gravity itself, still remains a constant, of course, but the length of time during which it acts increases its force-effect.

The alternative would be a jerky movement, in which the arm would move in spurts, resting between them. Such a movement is so obviously at a mechanical and physiological disadvantage that we can at once exclude it from consideration.

In recording slow movements, therefore, we may expect to find a less intense but more prolonged muscular contraction than in rapid movements. And, as the speed of movement increases, the initial muscular contraction should become more and more noticeable.

I have selected, for the purpose of recording, the contraction of the *pectoralis major*. This muscle was chosen for several reasons: first, because, as it passes the front of the arm-pit, it is superficial enough, and its contraction sufficiently marked to transmit readily the movement to an appropriately arranged tambour; and, in the second place, because the *pectoralis major* is directly involved in the lateral shifts of the arm (octave leaps and the like), that form an important part of pianistic movements, as well as in all forced arm-drops, a type of movement described in detail later. The muscle is situated below the collar-bone, spreading out from the forward side of the arm-pit in a fan-like manner over the upper side of the chest. It condenses considerably as it passes beneath and around the lower front of the arm-pit to its insertion in the humerus, and the turn taken at the arm-pit makes its contraction very noticeable. (See Fig. 176.)

The method of recording the muscular contractions was the following: To one end of a rubber tube a tambour was attached. This consisted of a shallow disk covered with very thin sheet rubber, to the centre of which a writing lever was fastened. To the other end of the tube a specially constructed plunger was fastened. This consisted of a small cylinder carrying a piston head and rod and working with a minimum of friction. The return of the piston to any original position was insured by the attachment of a sensitive spring. The whole apparatus thus made practically an air-tight chamber and any outside pressure forcing the piston into the cylinder would send a wave of condensation to the tambour, pressing out the sheet rubber and lifting the writing end of the lever. Such an instrument is sufficiently sensitive to record the contractions here measured. The writing lever rested upon a revolving drum which recorded any deflections of the point. When the piston is held firmly, and at the proper place and angle, against the muscle or tendon whose contractions are to be recorded, it will transmit these to the tambour, as it is pressed in when the muscle contracts. Its position against the muscle may be better fixed by a small bipod resting upon two points of the chest or side. Then any bodily movements (other than the muscular contraction to be recorded) will not cause deflection of the recording needle.

If the definition given of coördination as a muscular reaction serving the aim of the movement with a minimum of waste of energy, is correct, it follows that this reaction will change with the speed of the movement, because as the speed changes, the work done changes also, and consequently demands a change in muscular reaction, if this is to retain its maximal efficiency. This change may take place in either of two ways: the same muscles may contract more forcibly, thus increasing the output of work, or the muscular reaction may spread to adjoining muscles. If the first be the case, then we may rightfully speak of a fixed muscular reaction to any definite movement regardless of its speed. In earlier chapters the effect of range on coördination has already been pointed out. It was shown that as the range increases new muscles are brought into play, and that all movements of reasonable range, involve quite a transition of muscular activity, so that the combination of muscles functioning at the end of a movement is frequently quite different from those initiating the movement. We have now to determine whether speed has a similar effect. Let us assume an arm-weight at five pounds. This is to be moved through a distance of two feet in one second, and the work is done by a certain group of muscles. To move the same weight

through the same distance in half the time will require twice the force, and the additional force must be balanced at appropriate points by a spread of tension in order to give fixed fulcra to the contraction. The presence of this spread with any increase in force, has already been pointed out. It may also be readily inferred from the nature, size, and positions of the muscles themselves. If force variations depended solely upon intensity of contraction, large muscles would be superfluous, since the small muscles could do the necessary work by a more forceful contraction. Both anatomy and physiology show clearly that this is not true. The correlation between forceful movements and large muscles, light movements and small muscles is a fact recognized by all physiologists. Accordingly, as the force increases we may expect to find the larger muscles contributing more and more to the movement.

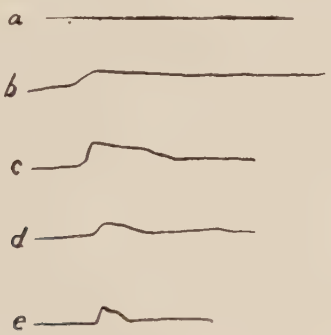

FIG. 33.

The pectoralis major is one such muscle. It is the most powerful of the arm adductors and its contraction is very noticeable in such potential movements as that represented by pressing the hands together firmly in front of the chest. But it is not the only adductor, and hence does not contract for all movements of adduction. The slower movements of this type do not require the force demanded by rapid movements.

Fig. 33 shows the effect of speed upon the contraction of the pectoralis major. The movement recorded was a lateral shift of two octaves, from C3 to middle C, with the player seated in the normal position before the keyboard. In record *a*, the movement was made in one second, necessitating a very slow arm movement. In *b*, the movement was made in three-fourths of a second; in *c*, in one-half; in *d*, in one-quarter: and *e*, in one-eighth of a second.

No contraction is noticeable in *a*. In *b* the contraction is slight and extends through an appreciable time interval, shown by the horizontal distance covered before the line drops back to the relaxation point. In *c* the contraction is more marked, and of less duration, a relationship shown more clearly in *d* and *e*. (Minor variations in these curves should not be used for interpretation since, in all probability they were caused by slight bodily movements and minute, undesirable fluctuations in the air pressure of the recording tambour.) Since in all cases the range and the direction of movement remained constant, and only the speed varied, the changes in the muscular reaction result from these speed variations. The greater the speed, hence the force required to produce the speed, the more is the work done by larger, more basically situated muscles. Moreover, the type of muscular reaction changes also. When the muscle begins to take part in the movement, its contraction is relatively slow and is maintained somewhat. When the speed of movement increases beyond this point the muscle contracts more forcibly, but also more quickly and this degree of contraction is not maintained. That explains the peaks in Fig. 33*d*, *e*, compared to the plateaux in *b* and *c* of the same figure. The mechanical and coördinative reason for this is explained on p. 104. It enables the organism to do the same work with less expenditure of energy.

Accordingly, as the speed of movement increases, the muscular contraction assumes more and more the nature of a twitch (not in a strict physiological sense, for all voluntary movement is tetanic in character) or "whipped" effect and the relaxation that follows almost immediately, causes the arm to travel as a relatively free body, given its maximum impetus at the beginning of the movement. We have here the explanation of the *Schleuder* and *Wurf-Bewegungen* which play such an important part in modern German piano pedagogy.

This effect of speed is noticeable in any movement the muscular contraction of which can be adequately observed. It explains, for instance, why the carpal extensors cannot be felt to contract until the extension of the hand is done rapidly, or why the flexors of the wrist contract only if the extension of the fingers be rapid. When these movements are made slowly the contraction may consume more time, hence the need of maximal contraction is not present. The tendons therefore, will not "snap" into a taut position and their contraction will not be noticeable. And besides, unless the force required to move the mass within the given time be sufficiently great, these fore-arm muscles may not contract at all. The mechanical need for such shifts in muscular reaction with

variations in the force of movement is explained in the chapter on Action and Reaction. The effects we are here studying are speed effects, but variations in speed, so long as mass remains constant are variations in force.

But a free body, as here understood, would be an uncontrolled body. Therefore, toward the end of the movement, a compensatory or modifying reaction must take place in order to lead the movement to the desired goal. And the same muscle that contracts in order to initiate a movement, will contract also to inhibit another movement in the opposite direction. If the pectoralis major contracts to bring the arm rapidly toward the body, it must contract also to stop the rapidly outgoing arm. This contraction is shown in Fig. 34. The movement made was the reverse of that used in Fig. 33. The shift made was from middle C to C3, at a high velocity, and was purposely brought to an abrupt stop; that is to say, the original impetus given to the arm was considerably more than that required to bring the arm up to the stopping point, three-lined C. The movement had to be inhibited in order to keep the hand from passing beyond this point. When this inhibition is

Fig. 34.

absent, and the "thrown" arm is allowed to travel on freely, until its own length and gravity change the direction of movement to a fall, the contraction of the muscle is absent. It is likewise absent if the hand or arm be allowed to strike an outside obstacle, such as a cushion. In this case one must be very careful to avoid any inhibition which the knowledge of the presence of an obstacle will naturally produce through the fear of pain, and must let the arm fly entirely freely against the obstacle. Fig. 34*a*, shows the contraction of the pectoralis major when voluntary inhibition takes place; *b*, the absence of contraction when the force of the movement is allowed to expend itself freely, or against an obstacle. Eight strokes were made, four with muscular inhibition and four against an outside obstacle, in this case a cushion placed at the point where the movement ended. The muscular contractions for the four voluntarily inhibited strokes are seen clearly; the arrows point to the four free strokes, where, if there had been muscular contraction it would have deflected the recording point similarly to the four points in *a*. Under the first arrow a slight deflection is still noticeable, caused by a fear reaction against the

imaged pain from striking an obstacle forcibly. The elimination of such a contraction must be assured, and at times requires considerable practice.

The purpose of the contraction of this muscle, namely, inhibition of the movements, is revealed also by the time at which it occurs. When the contraction initiates a movement it obviously occurs at the beginning; when it retards a movement of any appreciable duration, it occurs after the beginning. In Fig. 35 the duration

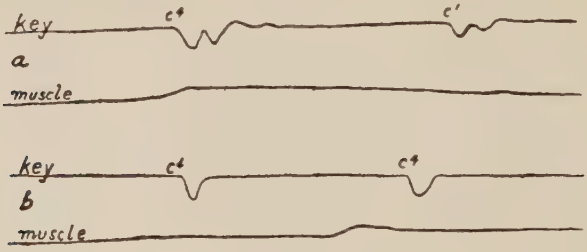

Fig. 35.

of movement is shown between the two deflections in the key-line. In *a*, the muscular contraction coincides with the beginning of movement since it causes the movement; in *b*, on the other hand, it inhibits the movement and, accordingly, occurs near the end of the stroke.

This manner of muscular contraction is independent of the direction in which the movement occurs. The lower part of the

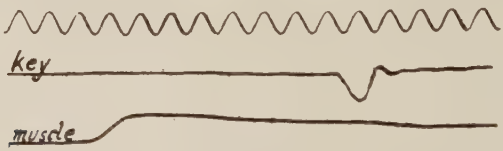

Fig. 36.

pectoralis major acts as a depressor of the arm. Hence, by holding the pneumatic tambour against the tendon we can record its contraction for arm-descent. When a chord is played *fortissimo*, the arm is forced down, the action of gravity being insufficient, within the range of movement, to produce the desired velocity. Fig. 36 shows at what part of the stroke the contraction of the pectoralis major takes place in such a vertical arm-stroke. In this particular record sixteen one-hundredths of a second elapse

between the contraction of the muscle and the depression of the piano-key. Moreover, muscular relaxation has already set in by the time the key is reached. This is in agreement with the contraction in lateral arm-movement and points to the initial contraction as typical in all rapid movements.

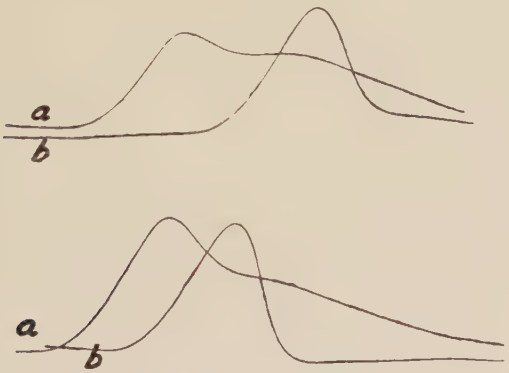

Fig. 37.

If this be true we may expect to find the time-relationship present also in finger-strokes. These strokes being of considerably less range than the arm-strokes just considered, make the actual time between the contraction of the muscle and the end of the stroke proportionately less. But if the recording be made sufficiently sensitive as to time, the differences may be seen.

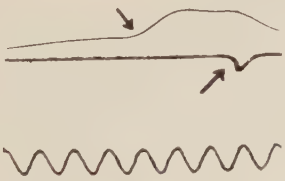

Fig. 38.

In the figures here given the contraction of the deep flexor of the fingers (flexor profundis digitorum) was recorded. This muscle is one of the chief finger-flexors, and its tendon as it passes the wrist is sufficiently superficial to permit recording by the instrument shown in Fig. 29. The end of the stroke was recorded by an electric contact. Before illustrating the time-relationships, I include Fig. 37 showing two types of contraction of this muscle,

highly magnified. The curves are lettered according to the speed of finger-descent, *a*, slow, *b*, very rapid. As the speed is increased the sustained contraction is replaced by the familiar "twitch", followed by a pronounced relaxation.

Fig. 38 illustrates the relationship between this initial contraction, and the end of the finger-stroke. The upper line in the figure shows the muscle contractions, the deflection in the lower line shows the end of the finger-stroke. Accordingly, in the movements here recorded approximately from two- to three-fiftieths of a second elapsed between the maximum muscular contraction and the end of the stroke. The difference is very small, but some difference was found in all cases. The principle deduced for arm-movements, therefore, holds for finger-movements as well. And in these two physiological units, the whole-arm and the finger, we have the largest and smallest playing-units used in piano technique. Time-relationship between muscular contraction and duration of stroke may, therefore, be considered a basic element of coördination.

The observations on the large muscles with movements of wide range can be made without the use of recording apparatus, by placing the non-moving hand firmly against the muscle the contraction of which is to be observed. Care must be taken, however, against altering the movement by directing the attention to the expected contraction. For this reason the observation is better made by a person other than the one making the movement itself. But the time interval and the range of the smaller movements are much too small to be detected by general observation. Here recording apparatus is needed.

Thus far we may formulate as principles of coördination :—

(1) The time-relationship between the muscular reaction and the duration of a movement is not a constant.

(2) Muscular contraction does not parallel the range of movement as speed increases. The faster the movement, the more does the muscular contraction approach an initial maximal "twitch" followed by relaxation.

(3) In all fast movements covering the greater part of the range of movement at any joint, the moving part traverses a part of the distance relatively free from muscular action.

Force Effects.

Since all pianistic effects are secured through variations in speed and force, it is necessary to investigate the effects of intensity upon coördinated and incoördinated movements. The speed effects which we have just considered in themselves point the way

to intensity effects, because variations in either factor influence directly the other. An increase in speed, if the mass remains constant, results in an increase in force ; and conversely, an increase in force, with constant mass, results in an increase in speed. We cannot, therefore, vary one without varying the other. There are certain phases of the problem, however, that can be better explained by a separate analysis.

Chief among these is the spread of activity with an increase of force, characteristic of all coördinated movements. The mechanical reason for such a spread of muscular activity is readily seen. Muscles do their best work along the middle of their range of action. Extreme contraction, when it does not actually injure the muscle or tear its tendon, does not permit the muscle to act at its greatest mechanical advantage. The function of the larger muscles of the body is not only to move the larger limbs, but also to aid in other forceful movements. Inertia, and resistance of flesh and tissue fix the joints passively up to a certain resistance. When more resistance is needed, muscular contraction at the joints occurs, fixing them actively against the increase in resistance demanded. Two views are possible. One that each muscle contracts until it exerts its maximal force, whereupon adjoining, more basically situated, larger muscles contract in turn, each waiting for maximal contraction of its predecessor before taking part in the movement. The other view is that the spread to other muscles takes place before maximal contraction of any one muscle is reached. The latter view agrees more closely with the facts.

What happens is this : As the intensity or resistance to be overcome increases, the parts of the body are so shifted that the force acts at the most advantageous part of the leverage system. When, for example, the entire body is suspended by the flexors of the fingers, as in hanging from a horizontal bar, the wrist is in line with the arm and the bar so held that it acts most directly against the first interphalangeal joint itself. Thus tissues and above all the skeletal structure is opposed to the force, which considerably lessens the strain on the muscles. When a chord on the piano is played *fortissimo*, the hand is so held, as we shall see later, that the direction of key-resistance is toward the hand-knuckle itself, with a tendency to push the bone-ends together. This gives maximal strength to the movement without maximal contraction of the muscles of the fingers, which, in themselves, would be too weak to produce the desired intensity. The larger muscles of the arm step in and take over the task, while the smaller hand-muscles place the finger-bones in such a position that when the blow is

struck the resistance will spend itself against the finger-joints themselves, that is to say, the skeletal part of the structure, so far as possible. (See Figs. 186 and 187*b*.)

The spread of activity to other muscles as the intensity of the movement varies is not restricted to any particular type of movement or group of muscles but is a characteristic of coördination itself. We find it in the spread from finger to hand muscles, as the resistance against the fingers is increased ; from the small supinator to the biceps with an increase of resistance against supination ; and from biceps to pectoralis major as resistance to elbow flexion is ncrea ed. But we may not conclude from this that the spread takes place only after maximal contraction of the preceding muscle has been completed, because the spread is frequently for purposes of joint-fixation. Thus I found, in the la'eral shift along the keyboard, toward its centre, that the biceps continued to contract further, after the pectoralis major had begun to contract. That is because the pectoralis has nothing to do directly with flexing the elbow (since its tendon does not cross the elbow-joint), but fixes the position of the humerus, so that, when the biceps contract more strongly, the humerus will not be pulled out of position. The mechanical principle at work here is more carefully analysed under Action and Reaction. The spread is normally toward the fundamental (larger) muscles, never the reverse.

A coördinated movement, therefore, considered in its force or intensity phase, is one in which the parts of the body involved act at the best mechanical advantage. As the force of the movement increases, the direction-relationships of the various parts of the body change. A hand-position, for example, adequate and efficient for a soft tone degree, may be entirely inadequate for the production of a much louder tone. In order for the finger-t p to exert its full force upon the key the extensors of the wrist must contract to prevent the upward movement of the wrist. The extent of this wrist-ascent determines the amount of force lost at the finger-tip. A few examples from general observation may be mentioned. In pressing against resistance in front of the body, the arms are held straight in front, not bent at the elbows. The resistance thus pushes against a straight line of bone into the shoulder socket. In the tug of war, the body assumes as nearly as possible a straight-line position so that the entire skeleton is opposed to the resistance. In " putting the shoulder to the wheel ", trunk and legs are in one line, thus gaining maximal mechanical advantage for the skeletal parts. In piano-playing such effects are not so readily observed because the movements are much finer. The subsequent chapters,

however, will furnish ample proof that the same principle operates in playing.

This shifting of parts in order to secure maximal mechanical advantage with minimal muscular expenditure is entirely in agreement with the definition of coördination already given. And conversely, an incoördinated movement considered in its intensity aspect, is one in which the parts of the body involved do not assume the best mechanical relationships.

As the intensity of a movement increases, therefore, the individual muscles acting do not necessarily do so at their maximal strength. The change in the spatial position of the bones relieves the muscles of this necessity. If this were not so, then the small finger muscles would have to be able to withstand the effect of the most powerful contraction of the large shoulder muscles. It would then be an application of the principle that a chain is merely as strong as its weakest link. Since whatever force the shoulder muscles create must be transmitted to the piano-key through the fingers, no single joint can be relaxed to a point less than the value of this force.

The fallacy of constant isolation is thus once again shown, the amount of relative isolation varying with each change in the force of the movement.

Range.

The shift of muscular activity varies, further, with the range of the movement. The extensors of the fingers, when finger extension has reached its maximum, bend the wrist backward (dorsal flexion); the extensor of the elbow is followed by the rear adductors of the humerus, when the movement is extensive; the deep flexor of the finger (flex. prof. dig.) flexes first the third phalanx, and then as the range of movement increases it flexes in turn, the second and the first phalanx, and finally the wrist. This spread of movement results from the passage of the tendon over the intervening joints and is a mechanical necessity. The mechanical arm described in the chapter on Relaxation illustrates the muscular action very positively. If the string corresponding to the deep flexor of the finger be pulled slightly, it flexes the nail joint; if the pull continues it flexes the middle finger joint, then the hand-knuckle and finally the wrist.

Moreover, the multiplicity of function, as a result of which one muscle acts in various ways, affects the range of movement. Observations made upon the biceps, which flexes the elbow and supinates the fore-arm seem to indicate that when only one of these motions is made the other is not simply eliminated, but is

prevented by appropriate contraction of the antagonistic muscles. That is to say, if only flexion at the elbow be desired supination will be prevented by contraction of the pronating muscles, in this case the *pronator teres*. If the movement be extended to cover both supination and flexion, the contraction of the pronator is absent. If this conclusion be correct, it seems to support the theory of all-or-none action of muscle. The entire biceps contracts in either case, but the effect of its supinating part is neutralized by antagonistic contraction elsewhere. This part of the biceps, accordingly, is not in a state of relaxation. The line of action of a muscle is determined not by the muscle itself but by the position of the points of origin and insertion. Since these for any one muscle are fixed, it is scarcely possible that variations in the line of action can result from the contraction of only a part of the muscle.

The neutralization of the undesirable part of the action by contraction of the antagonistic muscles naturally results in a certain amount of fixation, and is further evidence that a coördinated movement is by no means necessarily a relaxed one. Whatever contraction of antagonistic muscle-groups is present is that much hypertension, but this, as a whole, remains coördinated. A similar condition exists in the relationship between the finger extensors and the wrist flexors ; and between the finger flexors and wrist extensors. In a forceful finger-stroke, for example, the ascent of the wrist is prevented by the contraction of the muscles that lift the hand backward at the wrist. The tendons of the finger-flexors likewise pass the wrist, and, as a result, fixation of the wrist occurs, commensurate with the force desired at the finger-tip. This interaction of forces is explained in Chapter VII, under Action and Reaction.

External Resistance.

Finally we have to consider what happens to a coördination when a moving part of the body strikes an obstacle. A simple case of this kind is offered by the finger-key impact, and in order to simplify the mechanical analysis, we shall consider the key immovable. This unnatural condition, as we shall see, in no way interferes with the mechanical principle involved.

If the analysis of tonus and relaxation be correct, and if, when the descending finger strikes the obstacle, additional force be acting upon the latter, there must be corresponding relaxation in the antagonistic muscles in any coördinated movement. As an illustration : If the finger strike the key with a force of 70 (assuming the total tonus value at 100) then the antagonists will be acting

with a force of 30. If, after key impact an additional force of 10 be exerted upon the key, there must be a corresponding decrease in force in the antagonistic muscles, which will then act with a force of 20. And since there has been no movement for the additional 10 units of force, the other 10 will represent so much slack or looseness. When the 10 units of downward acting force are released, the antagonistic muscles will take up their 10 units of slack, but there will be no actual finger-lift. This begins only after the 10 units of contraction have been covered. At this point the resistance of the finger-weight is introduced and results in a momentary jerk in the muscular contraction. After this point the contraction is smooth, since no new and sudden resistance is met during finger ascent.

This may be demonstrated as follows: Place the right hand upon a table and raise the elbow sufficiently to bend the hand backward at the wrist about thirty degrees. Now lift the third finger. Its tendon will contract and will form an easily visible ridge along the back of the hand. (See Fig. 31, showing this ridge.) Place the forefinger of the left hand firmly upon this about an inch in front of the wrist. Now let the lifted finger descend slowly. The tendon will relax. When the finger-tip reaches the table continue to press firmly against the table with the tip of the third finger. The tendon may then be pushed to either side. Now release the pressure upon the table, whereupon the tendon can be felt to " slide " back into a straight-line position and not until then does finger-lift begin. If, before this point has been reached, the pressure upon the tendon has been maintained at an angle, the tendon will be felt to slide along under the finger-tip, from the side, until its straight-line position has been reached. With the finger lifted, though not moving, it is not possible to push the tendon to either side appreciably. This is the looseness or " slack " to which I have referred. The greater the pressure against the fixed obstacle, the greater is this " looseness ".

A similar test can be made with the tendon of the elbow flexor. With the fore-arm resting horizontally upon a table in the supinated position (palm of the hand up), and a considerable weight in the hand so as to emphasize the contraction of the muscles, raise the hand. The tendon of the biceps muscle (which is a flexor of the elbow in the supinated position) will be seen to rise in the bend of the elbow. Take this tendon between the fingers and thumb of the left hand, and push it toward one side, not too strongly. So long as the weight is held in the lifted hand, the contraction of the tendon will not permit its position to be changed easily. Now let the hand

return to the table, and rest as before. The tendon will be felt to relax, and, when the arm is resting firmly upon the table, may readily be pushed aside. Once again prepare to lift the weight very slowly from the table by elbow flexion. The flexor-tendon will be felt to contract before the fore-arm begins to move. Suppose the fore-arm to weigh two pounds. A contraction sufficient to move one pound will, therefore, not move the fore-arm. As a matter of fact, the moment contraction begins work is being done, but in insufficient quantity to produce the desired effect. This may be seen by resting the fore-arm, volar side up, upon an appropriate balance. Then, just as soon as contraction of the tendon occurs, the balance will register a withdrawal of weight. The arm cannot leave the surface of the balance until the latter registers zero. Then the arm-lift, unsupported, begins. In the case of the balance as a rest, we cannot properly speak of looseness, because the resting surface actually ascends with the arm from the very beginning of weight-withdrawal. In the case of a firm rest, however, we have the condition of muscular contraction and no movement—a characteristic of incoördination since it produces "slack".

Since coördination means the muscular response doing a required amount of work in a given time with least waste of energy, the state of contraction of a muscle is independent of the mere position of the skeletal parts it moves. If the fore-arm be lifted with the hand carrying an additional weight, a greater muscular contraction will obviously be necessary to bring the hand into a desired position, than would be required to bring it into the same position without the weight. Both movements may be equally well coördinated, in spite of the possibly marked difference in muscular response. Here neither the range, nor speed, determines the muscular reaction, which is the result of the resistance to be overcome.

Moreover, the definition of coördination as minimal expenditure of energy for the end in view, determines also the range at which the movements will occur. In the study of the anatomical structure the increase of physiological resistance as the extremes of the range are approached was pointed out (p. 15 ff.). To overcome this added resistance will require additional energy, which, since it serves merely to overcome superfluous resistance, is itself wasted work. Consequently a coördinated movement is a movement which permits the joints involved to act as near to their mid-range of action as possible.

By keeping my fore-arm stationary, I can, with fully extended third finger, by abducting and adducting the hand at the wrist (see Fig. 14, Horizontal Movements) move my finger-tip through

eleven inches. But the movement, through at least two inches at each end, is awkward. I can move the finger through the same distance much more readily by adding upper-arm abduction or humerus rotation, or a little of each. In coördinated movements the avoidance of the extremes of range is responsible for the shift of muscular action as the movement continues. It also explains why, in practically all pianistic movements, motion at more than one joint takes place.

Large and Small Muscles.

It is at times possible to make the same movement by various muscles, and the question naturally arises as to which, in such a case, would be considered the coördinated and which the incoördinated movement. For example, in a short lateral shift of the hand, let us say of half an octave, should the movement be made by ab- and adduction of the wrist, slight extension and flexion of the elbow w th humerus rotation, or slight abduction of the upper arm ? The question cannot be answered definitely because too much depends upon the precise nature and aim of the lateral shift,

Fig. 39.

and upon preceding and succeeding movements. However, the principle holds that : Rapid movements and movements of small range are naturally adapted to the smaller muscles and joints, powerful movements and movements of wide range are adapted to the larger muscles and joints. It is true that large muscles are by no means lacking in the power to control fine movements. Fig. 39 is an example of writing when an ordinary fountain-pen is attached to the elbow. This necessitates writing with the upper arm entirely, yet, without any preliminary practice, the large shoulder muscles could control the strokes sufficiently to make the words readily legible. (Fig. 39 is approximately one-half the size of the original.)

The fact remains, however, that the work can be more economically and accurately done with the finer finger muscles. Largely, perhaps, because one element of coördinated movement is proper time. And so soon as a large mass is moved in various directions rapidly, the inevitable factors of inertia and momentum place the movement in the incoördinated class.

Rapidly repeated movements, the chief characteristics of which are speed and reversal of direction, play a prominent part in pianistic movements. In keeping with the principle outlined in the preceding paragraph, they should be played with the smallest parts of the arm. Staccato octaves, of weak or moderate intensity should be played from the wrist, using the hand as the moving part. If played from the elbow, the fore-arm weight is added to that of the hand and each change of direction must be accompanied by a proportionately greater muscular inhibition. The problems are frequently complicated by other considerations : ease of reach, the character of the preceding and succeeding passages, and the dynamic gradations ; but basically a movement requiring a rapid change of direction in the playing part should be made with as light a moving part as possible. It is for this reason that rapid arm-leaps with reversal of direction are so difficult : The necessary inhibition of momentum interferes with the freedom of the movement. This point brings up the interesting question of whether the pianistic vibrato touch should be classed as an incoördinated or a coördinated movement. (See Chapter XVI, under Vibrato.)

Time Relationship.

The economy of energy characteristic of all coördinated movements demands also that the agogic sequence of the parts of the movement, the time-relationship, among the various phases of the movement, be those of least waste of effort. Among other things this means that the contraction of a muscle should not continue after the work of the original contraction has been done. In piano-playing sustained contraction has at times a physiological value, but no mechanical or tonal advantage. On the string instruments, such as the violin, sustained contraction plays a most important part. Most movements of piano technique are rapid contractions followed by periods of relaxation. The ratio between the time of contraction and the time of relaxation is one measure of coördinated movement. In fact, I am inclined to believe that the readiness with which relaxation sets in between movements, be they movements of fingers, hand, or arm, is a fair index of kinesthetic talent as applied to the piano. At any rate I have always found, in watching the playing of technically talented, though pianistically untrained students, that a very nicely adjusted relaxation is always present immediately after tone-production. The opposite of this is an accepted fact : The sustained contraction (useless stiffness) of untalented pupils is pianistically undesirable. But the relaxation following tone-production has frequently, but erroneously,

been supposed to exist during tone-production as well, and has given rise to a pedagogy of tone-production that robs the player's style of much force, velocity, and brilliance. A coördinated movement, considered in its time phase, is one in which the muscular contraction is of as short duration as possible in view of the desired effect.

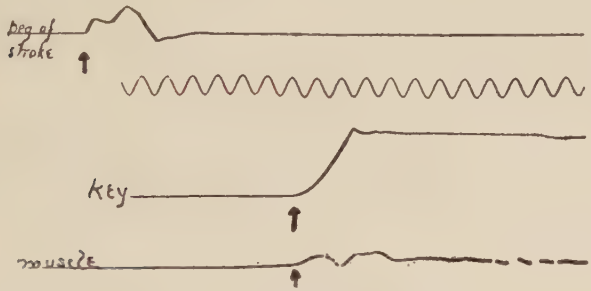

Fig. 40.

In Fig. 40 is shown an example of a well-coördinated movement At the beginning of the stroke the muscles opposing key-resistance (in this case the flexor carpi radialis) are not contracted until the key-resistance is met. The descent of the arm to key-level was done

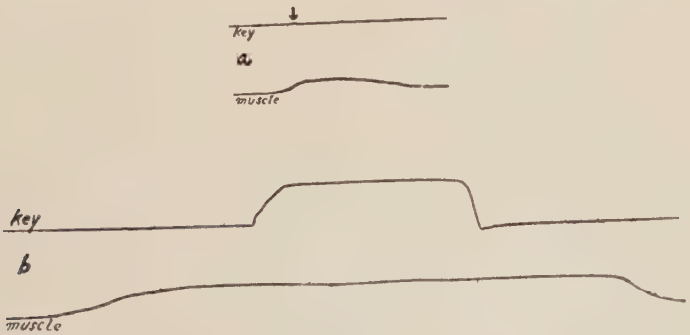

Fig. 41.

with a relaxed hand. The latter became fixed just before key-contact, in order to meet the key-resistance effectively. (See also Fig. 107.)

Compare this with the two records of Fig. 41. These represent incoördinated movements, as made by two untalented pupils.

In the first record, muscular contraction took place but it was opposed by simultaneous contraction of the antagonists. As a result, the original flexor contraction went for naught, since the key was not depressed at all. The key-surface was just about touched, hence the minute break in the key-line at the arrow. At *b* in Fig. 41, the muscle contracts long in advance of the key-contact, and remains contracted well after key-release. All of this premature contraction and the post-prolongation thereof, are wasted effort, not only producing no useful effect, but also seriously restricting other phases of movement.

This time-relationship of a coördinated movement may therefore be stated as follows : The contraction of a muscle should take place a moment before, or upon the introduction of the resistance which the muscle has to overcome. It should cease not later than removal of the resistance.

Antagonists and Synergists.

Antagonistic muscles are those whose actions are in mechanical opposition : If one muscle flexes the elbow, for example, its antagonist extends the elbow. Synergistic muscles are those acting at the same time in the production of movement. The term is sometimes restricted to the muscles aiding the principal muscle, but, since this distinction cannot always readily be made, I prefer to extend the definition to all muscles helping to produce the movement. Even so the classification is not always fixed. A muscle acting synergistically with regard to another muscle may act antagonistically to the same muscle in another movement. This probably never happens in motion in a single plane, that of a hinge-joint, but it frequently takes place at the rotary joints, and results from the fact that the change in the direction of the skeletal parts results in a change in the direction of the pull, since the origin of the muscle is fixed.

The reality of muscular antagonism can be experimentally shown in the case, for example, of a spinal animal, that is one from which the brain has been carefully removed. Here any movement is necessarily a spinal reflex. Under such conditions the stimulation of one set of muscles will be accompanied by relaxation in the antagonists. This relationship forms the basis of coördinated movement, and at the same time points out the reflex character of coördination, a fact that makes it unwise to attempt the teaching of a movement by calling attention to the actual muscles used. We do not, in ordinary use, feel or will the particular contraction.

If the proper resistance is present the proper contraction, in normal cases, will follow as a mechanical necessity. The fact that many untalented pupils do not adopt the proper muscular adjustment is an indication of subnormality in this respect. There are individual variations in the sensitivity and adaptation of the kinesthetic sense just as real as individual differences in vision or audition; of this the various ataxias give unmistakable evidence.

CHAPTER X

Relaxation

The close interrelationship between coördination and relaxation is evident from the analysis of coördination in Chapter IX. It makes a separate treatment of relaxation awkward, yet there are certain phases of the question which remain to be pointed out. These are the result of experimentation with a mechanical arm. I cannot urge too strongly the use of such an instrument : it reveals in a striking manner many widely accepted fallacies of the mechanics of arm-movement.

The criticism will immediately be made that such an instrument does not reproduce at all the complex physiological mechanics of the arm itself, hence its study cannot lead to practical conclusions. The premise is true enough, but not the conclusion. Since the joints of the fingers, wrist, and elbow are all hinge-joints, some entirely, and others primarily, a mechanical arm with hinge-joints reproduces faithfully the simple mechanics of the movement. A model of such an arm is shown in Fig. 42. Moreover, by attaching appropriate cords to the parts corresponding to the insertions of the tendons, and by approximating the lines of muscular pull, a study of muscular action may be made which is very helpful in the analysis of movement and joint-fixation. In the model here used, set screws at each joint permitted any degree of fixation, and the fact that such fixation produced the same results as fixation with the pull of antagonistic muscles is proof that immobility of joints is necessary to produce certain effects at the finger-tip.

Relaxation and Arm-Position.

Any position of the fore-arm, other than the vertical position at the side of the body, demands fixation of the humerus, so long as no part of the arm or hand rests upon a fixed point. This is the work of the shoulder muscles. If the humerus moves, the elbow necessarily moves. The fore-arm, in turn, is held in position by contraction of the muscles in the upper arm. Position of the back of the hand is fixed by contraction of the muscles in the fore-arm ; position of the fingers is fixed by muscles in the fore-arm and in the hand. Without this contraction the arm would hang limply at the side of the body. The mechanical arm, with all joints relaxed, lies horizontally on its base-board. If picked up at any

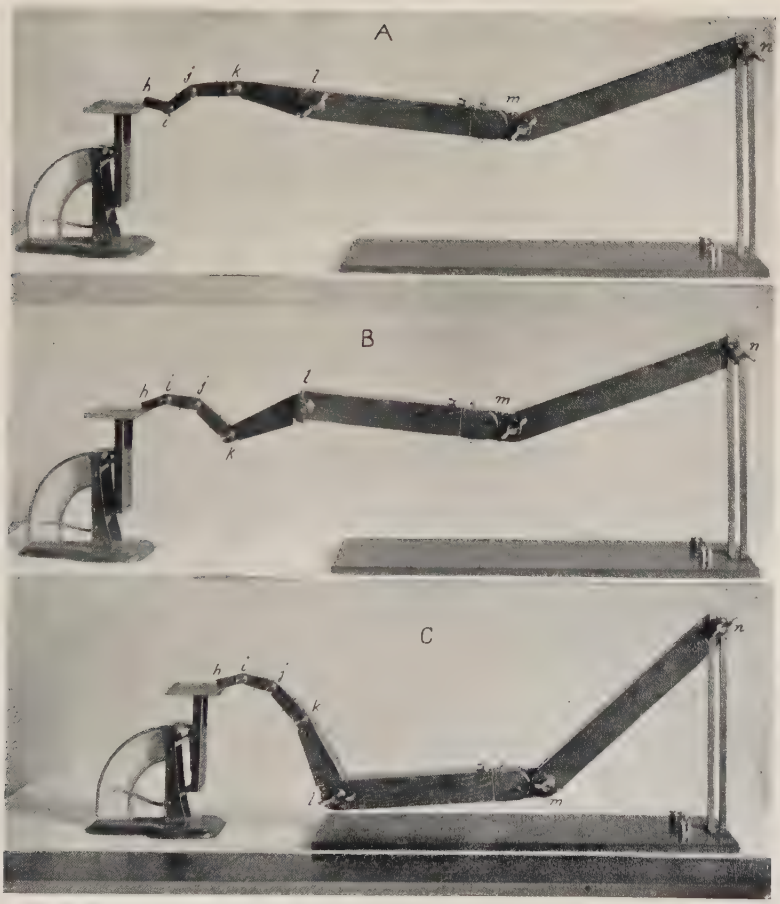

Fig. 42. A Mechanical Arm, showing effect of relaxation on joint-position.

[To face p. 124

point both sides approach a vertical in much the same manner as the links of a flexible chain. From these observations we may deduce as a first principle of controlled movement:

In order to maintain a joint at a given position in space, without external resistance at this point or at any intervening point, all other joints between this point and the trunk must be fixed to an extent sufficient to overcome the weight of the intervening parts. The shoulder supports the entire arm, the elbow supports the forearm and hand, the wrist supports the hand, and so on. And, since in all controlled movements some retention of position is necessary, relaxation in any pianistic touch-form is relative, being accompanied by a perceptible degree of fixation at all times.

When resistance is introduced at the finger-tip, so that this point, and some other point such as the shoulder become fixed, then relaxation in any single joint between these points of fixation will not affect the arm-position. Thus the mechanical arm, if any one joint is relaxed, but all others remain fixed, will not change its position at all. It does not follow, therefore, that movement at a joint will necessarily follow relaxation at that joint.

The spatial position of the parts changes radically, however, as soon as more than one joint is simultaneously relaxed. It makes no difference which two or more are relaxed. In each case the position of the parts is changed, and the form of this alteration, as well as its extent, depend upon the particular joints relaxed. In A of Fig. 42 the first (*i*) and second (*j*) interphalangeal joints are relaxed. As a result the nail-joint (*i*) "breaks in". In B of the same figure the hand-knuckle (*k*) and the wrist (*l*) are relaxed, whereupon the hand-knuckle sinks. In C, the wrist (*l*) and the shoulder (*n*) are relaxed and the arm part between the two, drops. The relaxed joints, therefore, need not be adjacent, one or more fixed joints may intervene, but movement occurs just the same. As soon as one of the two relaxed joints is fixed, however, all movement stops. Needless to say, in the illustrations the finger-tip (*h*) is fixed only in a vertical plane, movement in the other joints, pulls *h* toward *n* slightly. The spring-balance shows nicely an increase in weight at the finger-tip as the relaxed joint is shifted away from the finger, thus increasing the weight of the fixed part between the relaxed joint and the finger-tip. This weight increase is, among other things, proportional to the weight of the part of the arm between the relaxed joint and the finger-tip.

A second principle of relaxation thus becomes:

In order merely to maintain the finger-tip in a fixed position upon a key, not more than one joint may be in full relaxation

between this point and the shoulder-girdle. All other joints must be fixed at least to the point necessary to overcome the weight of the intervening parts.

This means that the mere " resting " of the arm upon the keys by means of the finger-tip, with the one exception of the purely vertical position, is not a relaxed arm-condition at all but one of mild fixation, most probably in all joints. It is equivalent to the difference between the free arm-drop and the controlled arm descent described in a later chapter. Moreover, the mechanical arm shows the direction that movements take when excess relaxation is present. I have several times referred to the fixation of the shoulder to keep the elbow sufficiently forward, thus preventing the hand from being pulled away from the keyboard. If the joint *n*, Fig. 42, which corresponds to the shoulder-joint, be relaxed, *m–n* drops to a vertical, thus pulling *h* and the ntervening joints away from their present position toward *n*. On the keyboard this would pull the finger-tip from the key. Every playing position in which the upper arm is in any but a vertical position demands some fixation at the shoulder socket in order to keep the upper arm from dropping to a vertical position at the side of the body. Thus the contraction of shoulder muscles is present in practically all playing, since the vertical humerus position is of negligible frequency in piano technique. On the other hand, if the problem be the teaching of a " relaxed " arm, the vertical position near the side of the body is preferable to a position with laterally extended elbow. In the former the shoulder is naturally relaxed, having no active mechanical work to do ; in the latter it cannot be completely relaxed because it has to maintain the position of the elbow against the action of gravity.

Fixation.

The mere maintenance of position according to the second principle just stated does not mean that work will be done at the finger-tip. With the finger-tip resting upon the key, the finger joints fixed and the hand-knuckle relaxed, the force exerted upon the key will be a part of the weight of the finger. This is a constant and cannot be modified without muscular contraction. We can increase it by shifting the point of relaxation into the wrist or elbow, and stiffening the hand-knuckle, but again, it will be a constant for either joint, once the shift is made. In order that more work may be done at the finger-tip, the flexors of the finger must contract, acting at *k* as a fulcrum, the position of *k* being fixed by the fixation at the wrist *l*. On the mechanical arm this

fixation may be gained by appropriate setting of the screw or tension of the cords representing muscular pull. The direct dependence of force at the finger-tip upon the rigidity of the joints of finger, hand, and arm is then clearly seen. With each increase in force the "break" at the joint of least fixation, other things equal, becomes more noticeable; and this can be overcome only by tightening the set-screws or increasing the pull of the cords representing the muscles. Such facts have been so well known in mechanics that their re-statement here becomes a truism; yet their absence in the doctrine of relaxation in piano-playing shows clearly that they have escaped detection. This is not surprising, because all such fixation is a necessary coördination; being constantly present in, and varying in a fixed way with each movement. The fixation itself, following a fundamental law of sensation and perception, is not present to consciousness. Thus a third principle of relaxation may be stated as follows:

In order that a force greater than the weight of the moving part be exerted upon the finger-tip, muscular contraction must be added to the weight, and the muscular contraction necessitates greater fixation in all joints acting as fulcra. The degree of fixation required is directly proportional to the force demanded at the finger-tip.

Weight Distribution.

The influence of arm-position on weight-distribution is mentioned in the chapter on Weight-Transfer. A few additional details, revealed when the mechanical arm is suspended in various positions by appropriate spring-balances, may be of interest.

The mechanical arm here used weighed approximately 35 ounces. With the arm horizontal and all joints fixed the vertical pull at the wrist in ounces was 17, at the elbow 11, and at the shoulder 7. With the finger flexed 90° in the hand-knuckle, the shortening of the arm-length was insufficient to affect the readings. (A more accurate scaling showed a loss of one-fifth of an ounce at the wrist and a similar gain at the shoulder.) With the hand hanging vertically at the wrist the readings were: wrist 16, elbow 11, shoulder 8. With a horizontal arm (joints fixed) hanging between finger and shoulder the weight at the finger-tip was 16·5 and at the shoulder 18·5 ounces. With horizontal fore-arm and elbow-humerus flexion of 45°, the weight was: finger, 15, shoulder 20. With horizontal fore-arm and vertical upper arm (hence elbow flexion of 90°) the weight at the finger-tip was 9, at the shoulder 26 ounces. By raising the wrist to 45°, and with elbow-flexion of 45° the weight

at the finger-tip was increased to 18, that at the shoulder reduced to 17 ounces. With the wrist 45° below key level, elbow flexion 45° as before, the finger registered 10 ounces, the shoulder 25. Finally with the arm straight, slanting forward and downward 45°, the weight at the finger was 17, at the shoulder 18 ounces. The absolute amounts of these measurements are of no value here, but the relationship among them, and the manner in which they vary, are the means of learning about the weight-transfer in playing. Fig. 43 is a diagrammatic illustration of the same mechanical principles which we have just measured. In the figure, A, B, D, G, are various positions of the arm, with *f* as finger-tip; *h* as hand-knuckle; *w* as wrist; *e* as elbow; *s* as shoulder; and *c* as the centre of gravity of the arm, which is just in front of the elbow. The heavy vertical lines show the direction of the force of gravity. The horizontal distances *f*-*c* and *s*-*c* are, therefore, the lever arms. In A the ratio of these arms is as 7 : 5; in B as 6·7 : 5; in D as 9 : 5; in G as 53 : 5. Since the forces exerted at the lever ends are in inverse ratio to the lever arms, least force will be exerted at *f* in G, next in D, then A, and most in B. The position usually pictured for the ideal position of arm-relaxation with weight-transfer, namely, that at G, is the least adapted to this transfer of weight, and the position best adapted, B, is the high-wrist position so often frowned upon by pedagogues. It follows that the key-depression for arm-weight must take place in the first half of arm-descent, before the wrist reaches a horizontal position. The actual tone-production takes place with the hand and fore-arm (not the humerus) between the positions shown in B and G. The final resting-position as at D, is not the position for tone-production. Weight is always lost with the lowering-wrist. I speak here of arm-weight, not the force which a contraction of the arm adductors can exert upon the descending arm.

A similar condition holds for the forward shift of the shoulder. It is frequently stated that the player should lean slightly forward so that the centre of gravity of the trunk will be brought nearer the keyboard and the weight thus used to better advantage. The shift of the centre of gravity alone does not help the weight one bit. In G, Fig. 43, the shoulder is directly over the elbow, further forward than in any of the other positions, yet the amount of weight transferred to the finger-tip is less than in any of the other positions. The only way in which the forward shift of a centre of gravity can affect the key, is by stiffening all intervening parts sufficiently to withstand the effect of this force. The gain in such a position is not in its effect on weight directly, but in the improve-

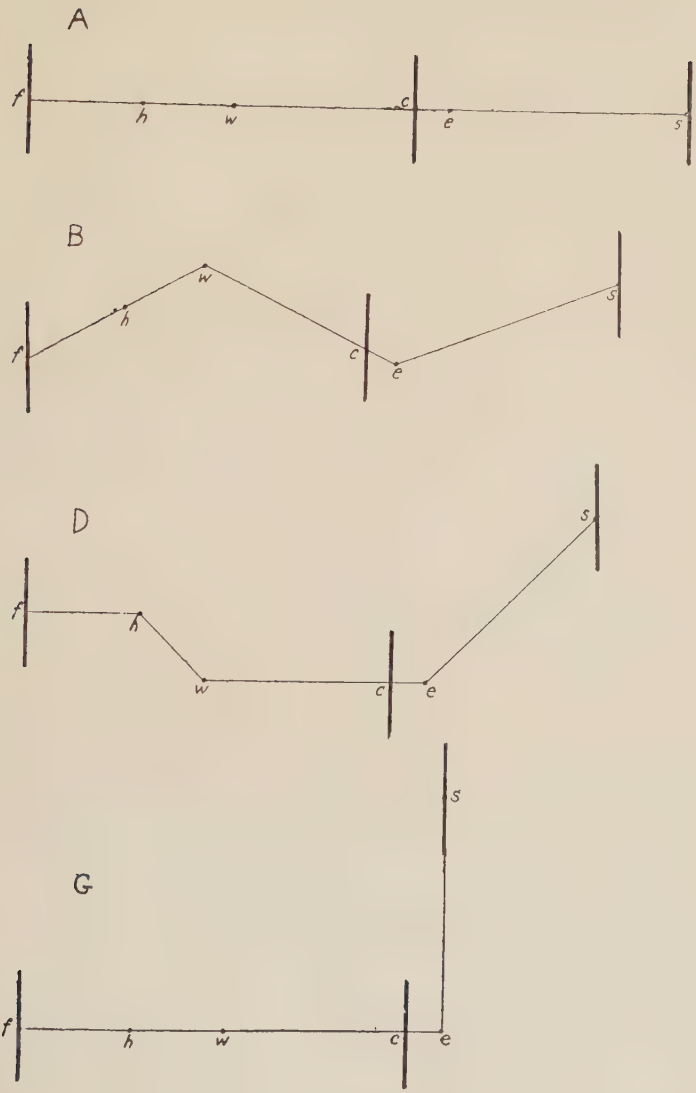

FIG. 43.

ment of the joint-position for taking care of the reaction of the force of finger-key impact. Friction and heat are generated now, instead of movement. It is the skeletal-straight-line position discussed under coördination, in which the force spends itself against bone-ends instead of against muscular pull. (See Plate XLIV.)

We cannot, therefore, correctly speak of mere relaxed weight-transfer. The force exerted upon the piano-key is not simply the weight of a free arm, but that resulting from an active contraction of muscles of fingers, hand, wrist, and elbow, plus the action of gravity. The nearer the shoulder is over the elbow, the less arm-weight can be directed to the key. The best position for directing the maximum amount of arm-weight into the key is that shown at B, where the wrist is high and the upper arm at a small descending angle. This requires a slight incline of the trunk away from the keyboard. If the trunk be leaned forward, the arm-position at G results, which is poorest for weight-transfer. The advantage of the forward position is in other phases, and its universal adoption by pianists proves that free arm-weight is probably never used in actual playing but is replaced by a muscular contraction added to gravity. In the chapters on arm-movement this question is discussed in detail.

Since this weight distribution is flatly opposed to the generally accepted arm-positions given in many treatises on weight technique, it is advisable to add an experiment that will enable anyone to verify the facts as here stated. Rest the cupped hand upon a balance so placed at the side of the body that the body may be moved forward and backward without exceeding the reach of the hand. Use the normal arm-relaxation of playing. If the experimenter is careful to avoid additional muscular contraction of the arm as the body moves, the dial on the balance will show an *increase* in weight as the body moves backward, away from the hand, and a *decrease* as it moves forward toward the balance. The reverse procedure : that of moving the balance toward and away from the shoulder, with stationary shoulder-joint, will show the same result.

The conditions change, however, when force is exerted by muscular contraction. In A of Fig. 43 a force at *f* works with a lever arm the length of which is *f-s*. Assuming this as a radius, any point, as *f*, will move through a great distance but will have proportionately less force, the work done being measured by the time and the distance through which the mass is moved. In G, the lever arm is considerably shorter. There is a loss in distance of displacement at *f* but a proportionate gain in force. Besides, in A, fixation of *e*, to prevent its rise when the key-resistance at *f* is

met, is difficult because this force acts at right angles to the line *e–s*, a relationship which is least adapted to application of force. In G the upward acting force at *e* acts directly along the bone in the line *e–s*, thus producing a condition of maximal efficiency : the skeletal straight-line position mentioned under coördination. In such muscular contractions, the weight of the upper arm is not actively used, hence its position is of no value. For that reason, position G becomes decidedly superior to A or even B. But position G is the typical " leaning forward " position accepted as the standard by most teachers. This acceptance, in itself, it seems to me, is a proof that normally, not arm-weight is used in piano-playing, but arm-stroke. Testing out the various arm-positions disclosed the fact that the tendency to produce reactive movement showed itself always at the joints the bones of which were in a straight angle, and deviated most from the line of action of the force. The earliest onset of movement takes place when the angle is a right angle. Fixation of the joint can change this, of course, but this does not exclude skeletal position as one determinant of the amount of muscular contraction. When two bones are in a straight line and the force acts along that line, less muscular contraction at that joint is required to withstand the force than if the bones were at an angle. (See angles of pull, Fig. 103.) The resulting principle is :

The amount of fixation or muscular contraction necessary to do work at the finger-tip depends upon the positions of the parts of the arm. It is greatest when the resistance acts at right angles to the longitudinal axis of the bone ; it is least when the resistance acts parallel to this axis.

Stiffness and Joint-Position.

Maximum force-effects demand, then, straight-line skeletal positions. We note it in jabbing with the finger, thrusting with the arm, and slanting of the entire body in the " tug-of-war ". The effect upon the organism of this relationship is an association between stiffness and a straight-joint. In children, with a tendency to stiffen in playing, it is advisable to avoid the straight-line position, so far as possible. The wrist, of all the joints, is most often used in this position, with the back of the hand forming a linear extension of the fore-arm. Such a position readily results in undue fixation, and conversely, the avoidance of such a position, by bending the wrist, preferably dorsally, frequently reduces the fixation.

Inertia.

There is yet another gain in position G, namely, the minimal effect of inertia. With the centre of gravity removed as far from

s as *c* in A, any change of direction in the movement by muscular contraction at *s* will require a maximum contraction because the muscles are working at a decidedly disadvantageous angle of pull. They have most of the arm-weight to overcome. In G, the weight of the upper arm is entirely eliminated, the muscles having to meet the inertia of only the fore-arm and hand, the lever-arm here being *c-e*, which equals *c-s*, measured horizontally. Inertia, in all complex piano passages, is of extraordinary importance, and its reduction to a minimum is most desirable. Such a reduction is secured by bringing the shoulder forward, more nearly over the keys. Again, the purpose of this position is not to add the weight of the upper relaxed arm, but actually to remove this weight. All movements requiring rapid repetition with reversal of direction demand for their efficient execution a minimal inertia. Rapid staccato octaves, played with the hand, are physiologically and mechanically superior to similar octaves played with the fore-arm, because the inertia of the moving mass is less when the hand alone moves, than when the fore-arm is added. The greater the inertia, the greater must be the muscular contraction to overcome it at any point where a change, particularly a reversal of direction, is required. And the greater the muscular contraction, the less the relative relaxation. This applies to a finger-stroke, hand-stroke, fore-arm stroke, or full-arm stroke.

In fact the attribute of inertia sets definite limits to the degree to which and the frequency with which relaxed arm-weight can be used in playing. So long as there is no change of direct on demanded, inertia is not a hindrance. But with each change in the direction of movement the mass is a factor of great importance. And since relatively few complex movements in piano-playing are straight-line movements, the necessity for reducing to a minimum the mass of the playing-unit, and through it, the inertia, is seen. The fundamental principle resulting from these mechanical relationships may be stated thus :

For speed and dexterity the mass of the playing-unit or units must be reduced to a minimum, a thing which requires a degree of fixation that makes impossible the relaxed arm necessary for arm-weight.

Nor is there any saving of muscular effort in resting the arm-weight on the keys. When the arm is poised over the keys the shoulder muscles carry its weight. When the finger-tip supports the arm, the shoulder muscles still carry a part of its weight, and the remaining part demands additional contraction of the wrist and finger-flexors to maintain the horizontal fore-arm position.

Thus the total amount of work done is the same, merely the distribution is different. The physiological value of resting upon the key is in this distribution. In each ascending arm movement the shoulder muscles do the work; by resting the finger on the key at the bottom of descent, some of this work is shifted to the hand and fore-arm muscles, thus resting the shoulder muscles for a moment.

CHAPTER XI

Weight-Transfer

The problem of arm-weight in piano technique and that of the transfer of this weight from one finger to another is so frequently met with in piano pedagogy, that a more detailed analysis of this question is desirable. The "Rollbewegung" (rolling motion) is based upon the assumption that the arm-weight is literally rolled from one finger to another. And the use of the weight touch in legato melodies, although it is not accompanied, necessarily, by a fore-arm rotation, likewise demands that whatever weight is being used for tone production be transferred from finger to finger as the melody is played. The mechanical principles already stated, and the conclusions reached in preceding chapters, indicate that this weight-transfer is not a simple, uniform mechanical operation, but one varying with other factors of technique.

Weight-transfer is the act of transferring a given weight from one point of support, let us say, finger-tip, to another. If the transfer be made without loss, or readjustment to make up for a momentary loss, we may say the transfer is perfect; if, on the other hand, there is considerable loss in weight as the transfer is made, and then a correction to adjust this undesirable loss, the transfer is poor.

For recording variations in weight-transfer, several types of dynamographs were used. In the records here given, vertical fluctuations record weight-fluctuations, a rise in the line indicating an increase in weight, a drop in the line a decrease in weight. A horizontal line then indicates perfect maintenance of a uniform weight, and the degree to which the curves deviate from such a horizontal line indicates the extent of the fluctuations in weight-transfer or maintenance.

The mechanics of weight-transfer may be briefly stated as follows:

The application of weight to the piano-key means a certain degree of muscular contraction. As this weight is transferred to another finger, the muscles controlling that finger are appropriately contracted in order to support the weight: and the muscular contraction for the first finger is correspondingly lessened as weight is released. If the relaxation for the first finger is greater than the

contraction for the second finger, weight is lost ; it is removed from the first key before the next finger is ready to take it up on the second key. But if the release is slower than the following contraction, there will be no loss of weight. Rather, there will be an overlapping of weight, which, on an instrument made to record weight fluctuations, will show in an actual increase in weight. On the keyboard it will result in unnecessary pressure upon one of the two keys. The unfortunate part of keyboard construction, one that makes the use of the normal keyboard impossible for the study of dynamic variations, is that, once the key is depressed, any additional pressure will not show itself, but will be spent against the unyielding resistance of the keybed. Variations occurring within this range are thus lost to observation, other than introspection, and the latter is relatively seldom dependable.

Mechanical Determinants.

Again, if the weight to be transferred is very small, it will require less extensive muscular adjustment than when it is large, since the small muscles of the fingers will suffice to make the transfer. Moreover, very little percussiveness need be used for this dynamic degree, which requires little force to produce the desired quantity of tone. The greater the amount of weight to be transferred, the greater is the muscular adjustment necessary for the transfer. The efficiency with which the transfer is made thus depends upon intensity : the actual quantity of weight to be shifted.

Percussiveness itself, we may expect, will interfere with the efficiency of weight-transfer. Experiment has shown that the judgment of weight is seriously hampered when any percussiveness is present, and, since weight-transfer is but another form of judgment between weights, this interference will certainly operate here too.

But percussiveness is not the only factor, as we shall see later. Since it takes time to transfer weight, that is to say, to withdraw it from one point of support and add it to the next, we may logically expect to find the efficiency of weight-transfer decreasing as the speed of successive finger-strokes increases. In rapid finger-strokes the time interval between any two successive strokes is too short to permit the transfer to take place smoothly, hence fluctuations are bound to occur. Fig. 44 shows the transfer of weight when percussiveness remains constant and only the speed varies. The record began with slow finger sequence (trill 2, 3, fingers). The speed was increased toward the middle and then again reduced toward the end, the percussiveness in the meantime remaining constant. The clearly marked variations in the efficiency of

weight-transfer are thus the result of speed, not of percussion, since speed here was the only variable.

Accordingly, weight-transfer may be expected to depend upon three factors: speed, intensity, and percussiveness. It is best in a non-percussive touch of low or moderate intensity, made at a slow tempo. For it takes time to make any muscular transfer; the amount of such transfer is greater in loud tones than in soft ones; and non-percussiveness eliminates the "shock" element

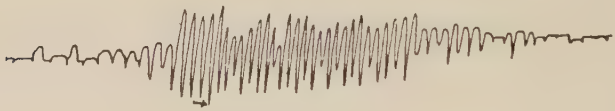

Fig. 44.

characteristic of all percussive touches. How much the transfer of weight depends upon these elements will be seen when we study various records of weight-transfer.

Such records may be secured by playing upon an appropriate lever, the amount of depression of which is controlled by a spring, and the deflection of which is transferred to a kymograph for recording. The amount of weight used will then be shown by the vertical displacements of the writing lever.

Effect of Intensity.

In order to measure the effect of intensity on the transfer of weight a series of trills were played at various dynamic degrees. The speed of finger-action was maximal in all cases, the subjects being instructed to trill just as fast as possible at all times. All those tested were experienced pianists. Fig. 45 shows a typical record in which four degrees of intensity were used. For the softest degree at *a* the finger speed was both greatest and the fluctuations in weight-transfer from finger to finger least. This is shown, respectively, by the number of deflections for any given horizontal distance, and by the height of the peaks in this line. As the intensity increases (from *a* to *d* in the figures), the number of strokes in a given time decreases and the fluctuations in the transfer of weight increase, so that when we get to the *forte* degrees (*d*), there is a noticeable reduction in finger-speed and noticeable fluctuations in the transfer of weight from finger to finger. Not only is there considerable loss of weight between each two strokes, but the amount lost varies

noticeably, resulting in a curve marked by both high peaks and irregular peaks.

In all cases, however, there is some transfer of weight, for at no point in any of the records does the low point reach the level of zero weight. Repeated trials in which the player made an attempt to neutralize this speed effect all showed similar curves. We may formulate the following law : At a given speed only a certain amount of weight can be transferred from one finger to another. In a *piano* or *pianissimo* trill it is possible, if the speed be not too great, to transfer the greater part of the weight used in the production of the tones, whereas in a loud trill only a very small part of the weight is transferred. It is physiologically impossible to transfer arm-weight in a loud trill. Such a trill is by its very nature primarily non-legato, so far as finger-stroke is concerned.

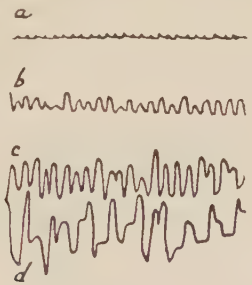

Fig. 45.

The mechanical reason for this condition lies in the property of momentum. Momentum is proportional to the product of the mass and velocity. By virtue of this property a moving body will continue to move in an unchanged direction unless acted upon by an external force. If considerable weight were transferred in a rapid *forte* trill we should have the paradoxical condition of a machine working at both a speed and a force advantage. This, of course, is a mechanical impossibility. In all leverage systems a gain in speed is accompanied by a proportionate loss in power ; a gain in power, by a loss in speed.

Effect of Speed. Finger Sequence.

For purposes of adequate analysis it is necessary to divide speed into two types : speed of finger-sequence, in which the same finger movement, and hence muscular group, is not immediately repeated ; and speed of muscular repetition. The degree to which weight is transferred from finger to finger depends upon the nature

of the finger sequence. If we take the trill as a typical instance of repeated movement, we find, that, in order to transfer the weight, the first finger must continue to act as support until the following finger has depressed the key. But, in a rapid trill—a slow finger alternation does not musically count as a trill—the first finger must also, as soon as the second finger has produced tone, repeat its own tone. If it be held down until the second finger is played, a condition absolutely essential to weight-transfer, it will obviously not be in as favourable a position for stroke repetition as when it is lifted slightly in advance of tone production with the other finger. Time is therefore lost before the stroke can be repeated, and, as a result, the speed of the trill is reduced. Fig. 47 shows that in a rapid figure involving repetition (hence also a trill) all fingers are constantly in motion. *a* in this figure represents a very slow sequence of second, third, and fourth fingers. From *a* to *c* represents a gradual increase in speed, *c* itself being a very rapid sequence. Fig. 46 also illustrates speed-effects.

If, on the other hand, the speed of the trill must be retained, less weight will be transferred from finger to finger, or, what amounts to the same thing, the trill will be physiologically non-legato. A rapid trill with considerable weight-transfer is a physiological impossibility. This is seen in Fig. 45, showing the effect of intensity on speed and accuracy.

The following illustrations, Fig. 46, are a record of trills made at various speeds. Although the subjects were instructed to maintain a constant weight-transfer, they all after a few trials realized the impossibility of doing this at any considerable speed. Fig. 46*a* shows the transfer of weight from second to third finger and back again, when the finger-strokes followed one another at the rate of one per second. In *b* the rate of finger-stroke was $\frac{1}{2}''$, in *c* it was $\frac{1}{4}''$, in *d*, $\frac{1}{6}''$, and in *e*, $\frac{1}{8}''$. Vertical displacements, as in preceding records, show variations in the amount of weight transfer, and perfect transfer of weight would result in a horizontal line, whereas deviations from perfect transfer are shown directly by the extent to which the curve deviates from a straight horizontal line.

Inspection of these curves shows that weight-transfer becomes more difficult as the speed of finger-action is increased, when this movement involves speed of individual finger-repetition. For the slow finger-speed the weight-transfer is perfect, the upper line at *a* being an unbroken horizontal. The finger rate being one in each two-seconds, gives the player time to transfer "gradually" the weight from one finger to another. Practically the same condition holds when the rate of individual finger-stroke is one per second.

When the strokes follow at two per second, a slight variation at the moment of tone-production is noticeable, as may be seen by the points which break the curve in Fig. 46*c*. These adjustments are more pronounced in *d*, but the primary horizontality of the line is still evident. At *e*, the deviations destroy the horizontal continuity, and with the finger rate at eight per second, the weight-transfer is markedly influenced by the finger-repetition.

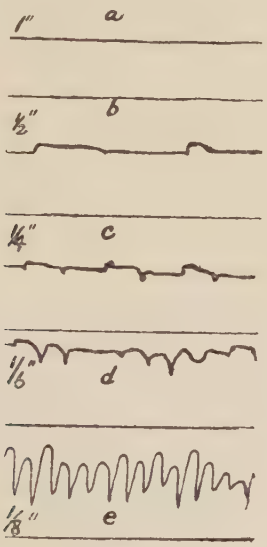

FIG. 46.

In all cases, however, some weight is transferred, since at no point in any of the records does the tracing point reach the zero level, shown by the faint lower horizontal line in each record. As finger-speed is increased, the amount of weight actually transferred at the moment of finger-impact deviates more and more from the total amount used. Moreover, since the vertical displacements in Fig. 46*e*, are practically all below the horizontal level at which the movement was started, the change of fingers at the rate stated involves a loss in weight, not a gain. This must mean that the weight is released by the first finger before the next finger is ready to carry it fully; a condition made necessary by the mechanical basis of the movement. Each finger-stroke consumes time, and if the rate of finger-sequence be so rapid that the times of finger-action overlap, a loss of weight in transfer is inevitable. The actual

existence of the overlap in finger-stroke is clearly shown also in Fig. 47, which records the movements of three fingers for varying rates of speed. For the most rapid notes all the fingers are in simultaneous motion. The fingers used were 2, 3, 4; and the tone sequence C–D–E–D–C. In A, Fig. 47, the strokes followed one another at the rate of approximately four-fifths of a second; in B, at one-third of a second; in C, at one-sixth of a second. The curves are direct tracings of the finger movement itself. In A the motion of each finger is, in point of time, an isolated movement, the two other fingers remaining at rest while the third moved.

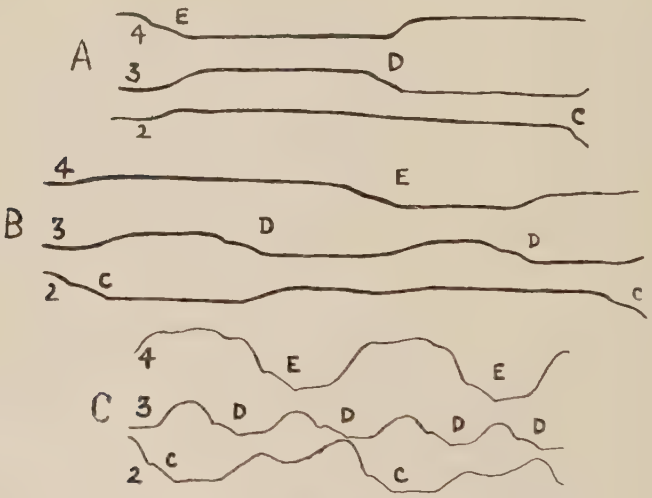

Fig. 47.

This is shown by the horizontal lines between the vertical displacements. In B, in the descending passage: E–D–C, the third finger is lifting as preparation for its down-stroke while the fourth finger is still descending. The plateaux noticeable in A are here shortened. That is to say, the fingers are not carried in a fixed lifted position. In C, no sign of fixed position remains. The three fingers are here in constant motion, shown by the absence of any horizontal lines. The mechanics and the coördination have thus changed completely. In A it is possible to keep the fourth finger depressed until after the third has played, thus transferring weight. But this is impossible in C, because the fourth is already lifted when the third plays. (See the point marked E, top line.) The muscular coördination,

in turn, must differ with the speed. The question of the extent to which slow practice is necessary for ultimate speed, when with every change in speed we change the muscular reaction, is an important one for the psychologist, and its answer awaits an adequate experimental investigation.

This variation in weight-transfer need not, however, affect the legato tone-sequence, because, so long as sufficient weight remains on the key to keep it even partly depressed (enough depression to keep the felt damper from actually touching the string), the tone will continue to sound. And in the middle region of the piano two to three ounces are sufficient. Fig. 44 gives a more vivid picture of fluctuations in weight-transfer resulting from variations in speed. It represents an *accelerando* and *ritardando* on a trill, with intensity and percussiveness relatively uniform. At the peak of the *accelerando* (which, by the way, was not steady in this case) the zero level of weight-transfer is actually touched in one point and almost touched in several others. This level is shown by the arrow.

Finger Repetition.

Thus far we have considered speed-effects as shown in repeated movements. We have now to consider these effects when the finger order does not involve individual finger repetition at a rate sufficiently rapid to interfere with weight-control. And if the explanation of the loss of weight-transfer for repeated strokes be true, we may expect to find much better weight-transfer when rapid finger repetition is eliminated, since, in this case, no need for rapidly lifting the fingers exists.

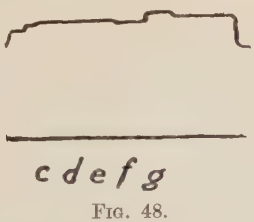

Fig. 48.

A simple form of such weight-transfer and finger-sequence may be seen by recording a tone-group such as the following: C, D, E, F, G, shown in Fig. 48. Regardless of speed, the weight-transfer is practically complete. The minute adjustments at the moment of finger-percussion are negligible in comparison with the amount of weight transferred, (distance between the two lines). In weight transfer the curve closely parallels the one in Fig. 46, *b*, showing

the trill at slow speed of repetition, although in Fig. 48 the finger-strokes followed at the rate of eight per second, whereas in Fig. 46, *b*, the rate was but two per second. Thus weight-transfer cannot depend upon speed of finger-stroke unless the element of rapid repetition is involved. Otherwise Fig. 48, at the rate of finger-action shown, would indicate marked fluctuations in the transfer of weight, such, for example, as are shown in Fig. 46, *e*, where the finger-speed is equal to that of Fig. 48. This being the case, we may expect to find similar weight-transfer if the direction of finger order is reversed: 5, 4, 3, 2, 1, and records made of this sequence bear this out. Here, too, the weight transfer is practically complete.

We may go a step further and record instances of actual increase in weight during the finger sequence, such as, for instance, that of a *crescendo*, while passing from C to G, and of a *diminuendo*. The results are given in Fig. 49.

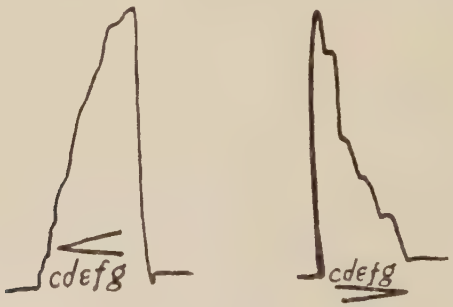

Fig. 49.

The weight increase is here approximately from 5 to 40 ounces. Needless to say, this was produced with the arm muscles primarily, and was not restricted to finger movements. It shows conclusively, however, that the efficiency of weight-transfer depends upon the particular figure involved and finally, upon the speed with which a specific single finger-movement is repeated. So soon as we introduce finger repetition into the figure the difficulty of weight-transfer is evident. The following group C–D–E–F–E–F–E–D, played with 1–2–3–4–3–4–3–2, produced, as a typical record, the curve shown in Fig. 50 where the pronounced fluctuations correspond to the trill between the third and the fourth fingers. This did not result from any incoördination of the fourth finger—the physiological awkwardness of which is well known—because similar fluctuations occurred with other fingers.

The more evenly distributed weight corresponds to the parts of the finger-sequence not involving finger repetition. This substantiates the conclusions drawn from the other records, namely, that efficiency of weight-control demands non-repetition of the finger-action. In rapid trills, it is impossible to transfer weight in any appreciable amount. In figures that do not involve finger

Fig. 50.

repetition in immediate succession, weight may be transferred without appreciable loss in speed, provided of course, that we do not demand a non-legato or staccato style. So long as a finger may remain in contact with its key until the next finger is played, weight-transfer is possible even at great speeds. When, however, the first finger cannot remain in contact with its key until the next finger plays, and this is the condition in all trill figures, mordents, turns and others, weight transfer is impossible for rapid speeds. Rapidity of finger repetition, not rapidity of successive strokes, therefore becomes the chief determinant of weight-transfer as measured in terms of speed.

Scales.

Since the speed of finger-lift is one determinant of weight-transfer, it follows that it functions in scale playing at the points where the thumb passes under the fingers or the hand over the thumb. In a rapid scale it is impossible to get the third finger out of the way (ascending, right hand) when the thumb plays and the second finger follows, unless it is lifted very quickly. This necessarily causes a break in weight-transfer, for precisely the same reason as that given for finger repetition, and illustrated in Fig. 50 for such fingerings as 1–2–3–4–3–4. Records made of rapid scale passages prove this conclusion to be true. Fig. 51 is a dynamograph record of the scale figures indicated by the fingerings given. A drop in the vertical displacements means a loss in weight-transfer. In both cases there is a decided drop down to the zero point where the thumb plays after the third or the fourth finger,

whereas up to this point there was a steady increase in weight-transfer shown by the gradual rise in the curves. The tempo was a *Presto*.

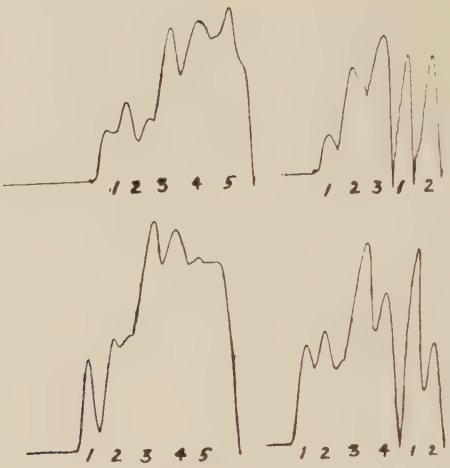

Fig. 51.

Effect of Percussiveness.

The third factor upon which weight-transfer is based is percussiveness. As we shall see when we study the records of the various touch-forms, the shock-element characteristic of all percussive touches destroys continuous contact of finger-tip and key, and upon this continuity of contact weight-transfer obviously depends. Fig. 52 is a dynamograph record and was made by keeping speed and intensity relatively constant and varying the degree of percussiveness. *a* was a non-percussive touch, and the unbroken top horizontal line shows complete weight-transfer from finger to finger. At *b* fluctuations at the moment of finger-impact begin to appear; they are more marked at *c*, while at *d*, where a decided percussive stroke was used, they show fluctuations both above and below the average level. The speed of finger sequence was but one per second, sufficiently slow to exclude speed effects, as *a* of Fig. 52 proves, where the same speed of finger-stroke shows no fluctuations. The horizontal lines at the bottom of each record show the level of zero weight. The effect of percussiveness is another illustration of the dependence of weight-transfer upon time interval. The momentary shock impulse does not give

the muscles time to make proper adjustment. If any adjustment is made, it is either insufficient or oversufficient, usually the latter. A sudden stimulus finds the organism unprepared to meet it and such a condition usually calls forth a maximal reaction in order to take care of great intensity, should the latter be present. If we add to this the fact that in percussive touches, as experiment has shown, finger-tip and key are not in contact after the moment of percussion, we can readily understand why accurate weight-transfer in a percussive touch is impossible.

The fact that we can hold a key and in spite of the percussive attack of a second key keep weight maintained does not contradict the principle just stated. In such a case we carry much excess

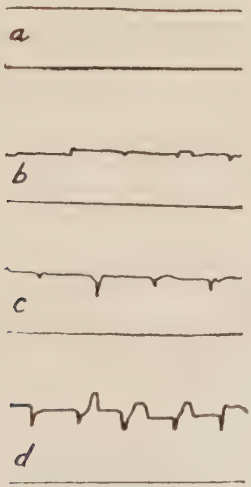

Fig. 52.

weight on the first key. When the second key is struck, the second force is added to the excess weight already present, but, since the movement of the piano-key is limited, will not show the typical percussive variation of the dynamograph. The actual transfer of weight then takes place after the percussion and consumes just as much time, in fact, slightly more, than in a non-percussive touch.

The three factors : speed, intensity, and percussiveness, however, do not affect weight-transfer to such an extent that no weight whatever is shifted from finger to finger. In none of the records,

with the exception of extreme degrees, do the fluctuations drop to the zero level. Some weight, therefore, is always transferred from stroke to stroke.

In the teaching of legato through the transfer of weight, the most favourable condition, accordingly, is one of very slow tempo, soft dynamic degree, and non-percussive touch. As we deviate from any part of this condition we inevitably increase the difficulty of the problem. The necessity for lightness has heretofore been overlooked because we normally think of quantity rather than smoothness in weight-transfer. If out of a pound of weight, one half pound is actually transferred, we have the feeling of considerable weight-transfer, in spite of the one-hundred per cent fluctuation involved. When, on the other hand, we transfer completely a few ounces, the feeling of transfer is less vivid, although the ratio of transferred weight to total weight is complete.

Should the pedagogic problem be the transfer of large quantities of weight, then the records show that a slow tempo and a non-percussive touch are advisable. And, if finally, rapidity of tempo becomes necessary, then a light touch and a non-percussive stroke are the easiest means of securing the effect.

Inertia.

Problems of weight-transfer cannot be dissociated from the physical attribute of inertia, which, under Mechanical Principles, is defined as that property of matter by virtue of which a body at rest tends to remain at rest, and a body in motion tends to remain in motion in the same direction and at the same velocity until acted upon by some other force. It takes force, therefore, to set a body into motion, and the heavier the body, the greater must be the force. In the second place it takes force to change the direction of a moving body, and again, the heavier the body, the greater the force required. Moreover, it takes time to do either, and the heavier the body the more time required by a given force to set it into motion or to change its motion. Assuming now that the weight of the arm is resting on the keys, any change from this position will require a greater force or will consume more time than if the arm is poised by contraction of the appropriate shoulder muscles. When the arm is in motion, any change of direction will require more force or time, since the inertia of the arm is greater. The interference of weight-transfer with speed is thus evident, and is the result not of a physiological difficulty but of a mechanical difficulty. The property of inertia likewise helps to determine the most economical form of touch to be used in the various pianistic movements.

Arm-weight.

Among the important problems of weight-transfer comes also the transfer of weight into the piano-key by the relaxed arm: "the arm hangs in the keys," as it has been aptly described. The supposition is that, in this position, the loosely hanging arm causes its weight to be transferred to the key. In the chapter on Relaxation I have pointed out the impossibility of using fully relaxed joints in any arm-position practicable for piano-playing. But the fallacy of "weight-transfer", as we have seen, goes further. Not only can there be no fully relaxed joint in any usable arm-position, but also only a part of the arm-weight, and usually only a small part, can be transferred to the finger in any condition. The shoulder continues to support the remainder, regardless of relaxation. Moreover, in the most favourable arm-movements of relaxation (see Fig. 43, D, G) the least weight can be transferred.

The variation of arm-weight with changes in the position of support may be observed by simply weighing the arm on some appropriate spring balance, preferably one without a fixed surface. A narrow sling attached to an ordinary spring balance will answer the purpose. If the sling hangs at approximately shoulder level, the weight recorded will become less as we move the sling from near the shoulder toward the hand and finger. The average for a series of measurements made of my own arm is, in pounds: midway between shoulder and elbow, 8·5; in crotch of elbow, 6·3; midway between elbow and wrist, 4·4; at wrist 3·5; in hook of second joint of the third finger 2·2. That is to say, the further the point of support is from the shoulder, with shoulder and point of support on a horizontal line, the less is the weight at the point of support. In the case cited the total arm-weight is approximately nine to ten pounds. When such an arm hangs freely, with the third finger hooked over a piano-key, less than one-fourth of the total arm-weight acts upon the key. Of course, the amount acting is still enough to produce a tone of moderate loudness, which may be augmented by increasing the range of arm-descent. But the key is by no means carrying the arm-weight, three-fourths of this is carried by the shoulder.

Since a position in which finger-tip and shoulder are horizontal does not occur in piano-playing, a measurement of the weight-distribution in the playing position is advisable. With the upper arm at an approximate vertical, and the fore-arm and hand horizontal, the elbow, in a specific case, carried a weight of 8 pounds, the mid fore-arm 4 pounds, the wrist $3\frac{1}{2}$, and the middle finger-joint 2 pounds. The proportions are approximately the same as before.

In order to throw more weight into the finger-tip some intervening joints must be fixed. And if the entire arm-weight were to be transferred, fixation of the whole arm between finger-tip and shoulder would be necessary. (See principle two, Relaxation.) But, even then, the whole weight could not be transferred on account of the position relationship between the two points, as a result of which the shoulder necessarily carries a part of the arm-weight. For with the humerus in an approximately vertical position at the side of the body, the head of the bone rests in the shoulder socket and gravity presses its under surface against the lower socket surface, thus tending to let the bone hang in the socket as a support. Moreover, the fixation of all intervening joints is diametrically opposed to the whole doctrine of weight-transfer, which demands a relaxed arm as a necessary physiological condition of this transfer. Exactly the opposite is mechanically true : weight-transfer demands fixation of the joints, not relaxation. Some additional details of the mechanical principles here involved have been given in the discussion on Relaxation.

CHAPTER XII

Vertical Arm-Movement

Arm-lift.

A perfectly relaxed arm hangs vertically at the side of the body when the latter is in a standing or sitting position. In order to make the arm useful for playing, it must be lifted to some point over the keyboard. This arm-lift takes place approximately as follows: The abductors and rotators of the upper arm, situated chiefly between the neck and the shoulder, contract to counteract the effect of gravity. In the case of abduction the upper arm lifts sidewise from the body, raising the elbow to a plane on a level with, or above the keyboard. In the case of forward rotation the upper arm rotates in the shoulder-socket, bringing the elbow forward and upward. The two movements are normally combined and involve the activity of practically the entire muscular system of the shoulder.

At the same time the elbow is flexed, and, if the hand originally was in the normal hand-position described on p. 32, some pronation in the radio-ulnar joint takes place. The combination of these movements will bring the hand over the keyboard, the exact point being determined by the degrees to which the various points of movement are involved. Thus with considerable abduction of the upper arm, slight forward rotation, and but little flexion of elbow, the right hand can readily reach the high treble, and the left hand, similarly, the low bass region. With less abduction and greater elbow-flexion the hand is brought over the middle part of the keyboard.

The hand itself will, under these conditions, hang limply from the wrist. Any attempt at control of hand or fingers will involve coördination of the muscular systems of the hand which will be added to the activity of the fore-arm, arm, and shoulder muscles. In any case, the lifting of the arm from any position below the keyboard to any position over it, and the holding of the hand in any playing position involves the muscular system of the entire arm. This is, perhaps, more convincingly shown by the fact that movement at any joint has occurred as soon as the angle between the bones forming the joint has been changed. In order to bring the arm over the keyboard the angle between body and upper arm,

that between upper arm and fore-arm, that between the plane of the hand and the direction of the upper arm, and for all practical tone-producing purposes, that between hand and fore-arm as well as those between fingers and hand, have all been changed. Consequently, movement has taken place in each joint and what apparently is a very simple movement is in reality a highly complex one. Since the movement is fundamentally in an ascending direction, it works against gravity and is an active movement. To speak of muscular isolation, therefore, in such a movement as a single finger-stroke, is to misrepresent the physiological condition; because, for any stroke whatever, the arm must first be lifted partly over the keyboard bringing into play muscles throughout arm and shoulder. Muscularly, isolation cannot exist. The widespread use of the term is the result of deducing a muscular condition from external appearance; of assuming that a joint at rest does not involve muscular activity. This is largely fallacious; in all forms of piano technique, as the preceding analysis of arm-lift shows, it is entirely wrong. It is true only when the arm hangs freely at the side, or otherwise rests upon some external object, and neither of these positions plays a part in piano technique.

Free Arm-Drop.

If the arm be permitted to drop from the lifted position just described, shoulder muscles are relaxed and gravity causes the arm to fall. Such a drop is an uncontrolled movement. Because the hand hangs vertically from the wrist, the tip of the third (longest) finger will be the first to touch the keys. The resistance of the key will then begin to retard the hand. Meanwhile the wrist continues its descent until finally the fingers rest flat on the keys. When the bending back of the wrist which follows this position, has reached its limit, the weight of the arm will pull the hand from the keys, the perfectly flat fingers sliding over the edge of the keys and the edge of the wooden casing beneath the keyboard. When the original vertical position of the arm is reached at the side of the body, momentum will carry the arm slightly beyond the perpendicular whereupon it will make a few small pendular swings before coming to rest. In this type of arm-drop, with fully relaxed arm, the keyboard merely arrests for a moment the descent of the hand. The movement is useless in practical piano-playing since it is uncontrolled. But it permits a conclusion to be drawn that is of importance in piano pedagogy, namely, that any arm-drop stopping with the hand on the keyboard is therefore a coördinated movement, with a certain amount of inhibition, not completely

free or relaxed. Even the position in which the palm of the hand rests against the wood casing beneath the keyboard is not maintained with entire arm relaxation. There is some finger flexion, causing the fingers to " hook " on the keys, and there is contraction of the forward arm-rotators serving to " jam " the fore-arm between the elbow and the casing of the piano by pulling the elbow forward. Otherwise the weight of the arm would pull the hand down from the keys.

The completely relaxed arm-drop, therefore, plays no part in piano technique, unless it be to intensify the feeling of relaxation in pupils working for this muscular condition. Its relation to the typical pianistic arm-drop is given in Fig. 53.

Modified or Controlled Arm-Descent.

What we have to deal with, then, in all descending movements of the arm as they are actually used in tone production on the piano, is a modified arm-drop, in which partial contraction of the muscle groups that lift the arm oppose gravity and hence slow down the descent of the arm. It is a condition of partial relaxation, not of complete relaxation, and is best known in piano parlance as the *portamento* tone-production.

The descent begins more gradually than that of the free arm-drop, and, throughout the descent the speed of the arm never quite reaches that of the free arm. As the hand approaches the keyboard, the fingers that are not to play are drawn back by contracting the extensor muscles, aided by the abductors, perhaps, while the flexors of the fingers that are to play, are likewise contracted so that these fingers will remain somewhat curved after they meet the resistance of the piano keys. If no attempt is made to avoid percussion, or at least to minimize it, there will be a distinct jerk in the descent of the arm when the fingers reach the keys, the abruptness of the jerk varying with the degree of fixation. If, on the other hand, the percussiveness be minimized by allowing the wrist to descend below the keyboard, the descent of the arm is gradually stopped and there are no angles to the movement. These differences are shown in Fig. 77, the curves *a* representing a well-controlled arm-drop, in which the wrist is depressed after the fingers strike the keys, and the curves *b* showing the effect of a rigid wrist. The grace and ease of relaxed movement is strikingly shown in the continuity of the two curves *a*. (See also Fig. 78.) Since in these records the speed of the recording kymograph was constant such curves show a very fine adjustment between time and movement. All effect of percussiveness has been eliminated and the arm-

descent is unbroken by any jerk. At the points where the lines begin to curve to the right, negative acceleration begins. That is to say, the speed of arm-descent is retarded. From this point on, the abductors of the arm contract, aided by the flexors of the elbow and the forward rotators of the shoulder as well as by the resistance which the keyboard offers to the fingers. Without this muscular action the weight of the arm would pull the wrist down until the hand reached its physiological limit of bending backwards (dorsi-flexion). The forward rotators of the shoulder contract somewhat in order to control elbow-movement away from the keyboard, as the fore-arm passes through its horizontal position. Without this action, the arch of the hand could not well be maintained. Slight contraction of the abductors of the arm keeps it from touching the side of the body. Thus inhibition of free movement occurs in all parts of the arm; at each joint muscles come into action to retard its free descent. This retardation must not be confused with stiffness, it is necessary for guiding the fingers and hand properly to their destination.

Whether the stiff or relaxed descent is preferable in practice must be determined by the particular effect desired. Physically, so far as fine tone control is concerned, the non-percussive character of the relaxed descent is undeniably better. And physiologically absence of shock is likewise desirable. On the other hand, the tonal intensity desired may make rigidity necessary, and with rigidity must come the shock of impact. In slow melodies of little or moderate intensity the relaxed form of tone-production with the arm-weight is preferable to a finger-stroke of similar intensity, because the finger-stroke, in order to transmit its force to the key, must have a fixed hand knuckle as fulcrum. This, in turn, demands a relatively fixed arm, and a similar spread of muscles is involved as when the arm-drop is used. Moreover, the percussiveness of the finger against the key has an undesirable effect upon the tone-quality, which is absent in the non-percussive arm-descent.

Forced Down-Stroke.

A third muscular type of arm-descent is that in which the muscles controlling the descent of the arm contract forcibly and, reënforced by the action of gravity, serve to lower the arm more rapidly than when gravity acts alone, as in the free arm-drop. Such down-strokes are used in piano-playing in the production of *fortissimo* chords, particularly when combined with a relative rapidity of tempo. The descent begins more abruptly and the speed is greater than in either case thus far considered. Fig. 53 shows a typical

curve *c* for the forced arm-stroke and, for the sake of comparison, a curve for free arm-drop *b* and one for controlled arm-drop *a*. The abrupt turn from horizontal to an approximate vertical path in *c* illustrates the rapidity of the beginning of the arm-descent, and the steepness of the curve shows the speed of the descent itself. In this figure the lines were traced by the wrist, with pantograph attachment. Moreover, since there is but very little additional bend toward the vertical, once the arm has attained its speed, let us say, at approximately one-third of the descent, it follows that, in the forced arm-stroke, the greater part of the stroke takes

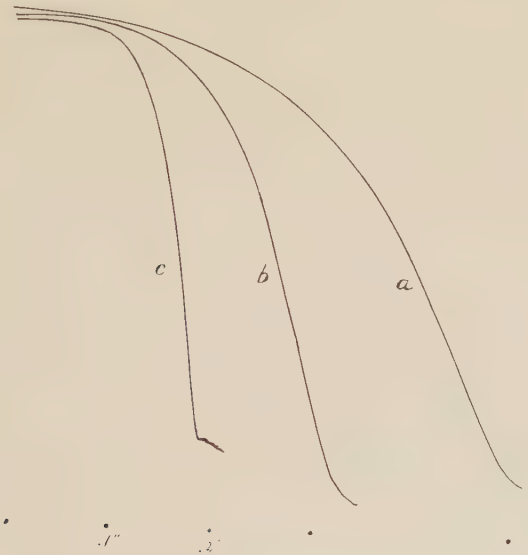

FIG. 53.

place at a constant speed. This means that additional force is not added during the movement, but the total force acts at practically the beginning of the movement. We may even go a step further and infer from this that the muscular force really ceases to act during the stroke since, if it were maintained at a constant throughout the arm-descent, the accelerating effect of gravity would deflect the lower part of the curve more toward the perpendicular. (The records for lateral arm-transfer throw interesting light on this phase.) In the forced stroke the arm is thrown or hurled (the *Wurf-* and *Schleuderbewegung* of the German pedagogues) by an initial, forceful and maximal muscular contraction, which is then

immediately followed by at least a partial relaxation during which the momentum given to the arm at the beginning of the stroke serves to carry it as a relatively free body through the remainder of its stroke. That produces uncontrolled movement except at the beginning of the descent, and means that, if the movement end as intended, a very fine degree of coördination is necessary at the beginning in order to send the arm on its correct path. (The final guiding to the goal is the work of other muscles. See Lateral Arm-Movement.) The difference between such a movement and the modified arm-drop is similar in principle to the difference between pushing a billiard ball slowly into a pocket, keeping the head of the cue in contact with the ball until the pocket is reached and rolling it into the pocket by giving it an appropriate cue-shot. In the first case, the direction may be changed at any point, in the second case, once the ball leaves the cue its course can no longer be modified by the cue. We have here the direct counterpart, on a larger scale, of the difference between non-percussive and percussive touch. In non-percussive touch the finger remains in contact with the key throughout its three-eighths inch of descent and, within this distance, any desired adjustment can be made during the course of the movement. In percussive touch, on the other hand, the finger strikes the key a blow, the duration of which is very brief indeed, being little more than instantaneous, so that the key is beyond the control of the finger after this impact. The effectiveness of the stroke thus depends entirely upon the appropriateness of the force with which the finger reaches the key.[1]

In the discussions of the effect of speed on muscular contraction, the reality of the initial maximal contraction is shown (Fig. 33). Fig. 53, recording as it does the actual path of the movement, offers further evidence of this type of contraction, the physiological and mechanical economy of which I have already pointed out. In the next chapter, on Lateral Arm-Movement, we shall learn how such thrown movements are modified as they near their end. This means that although the initiators of the movement no longer affect it after beginning, the modifiers may step in and direct the movement to the desired goal. In their action they do not have to work as active-antagonists to the initiators, for these have already ceased to act when the movement nears its end.

Arm-Drop

Effect of Tonal Intensity on Arm-Drop.

When the finger meets with the key-resistance this exerts an upward force which tends to retard the finger. In a tone-production

[1] Physical Basis of Piano Touch and Tone, op. cit.

with relaxed arm the finger touches the key while the wrist is still well above the level of the keyboard (a modified form of the "dangling" hand). By the time the finger-tip has depressed the key the wrist, in the touch-form we are now considering, is usually at a level with, or below the level of the keyboard. Accordingly, it must move much faster than the finger-tip. The latter traverses three-eighths of an inch, while the former traverses a distance varying between five and nine inches. But slow finger-speed means slow key-speed, and this in turn, produces a tone of small intensity.[1] So that, in order to increase the intensity of the tone, we must increase the speed of key-descent. This can most readily be done by decreasing the ratio between arm-speed and finger-speed ; in other words, by transferring more of the arm-speed

Fig. 54.

into the finger. For this transmission of force a lever of sufficient rigidity must be found ; and this is obtained by stiffening all joints between the original point of application of the force and the point of resistance. In the case in question these joints are the elbow, wrist, the hand-knuckles, and the finger-joints. The degree of stiffness is determined directly by the desired intensity of tone. For very loud tones the wrist is practically fixed, and is used without movement in the wrist-joint, so that the finger depresses the key at a speed equal to that of arm-descent. With even slight relaxation, there is some loss in speed between arm and finger, and hence, also some loss in tonal strength.

Fig. 53 shows the difference between the movements of a "relaxed"

[1] Physical Basis of Piano Touch and Tone, op. cit.

(*a*) and a rigid arm (*c*). Apart from a slightly greater speed for the rigid arm, the chief difference is seen in the ending of the curve, the gracefully retarded ending of the relaxed arm standing in marked contrast with the abrupt broken ending of the rigid arm. Accordingly, this abrupt ending, when the recording lever is attached to the wrist, becomes an index of the degree of rigidity present at this joint. Some records of wrist descent for various degrees of tonal intensity are shown in Fig. 54, as follows : $a = pp$; $b = p$; $c = mp$; $d = mf$; $e = f$; $f = ff$. Time intervals represented at the bottom of the figure are in intervals of two-tenths of a second. In the *pianissimo* tone production the wrist is completely relaxed, hence shows no break in the line of its descent. The same condition applies to the piano tone-production. In *mezzo-piano* the break in the curve indicates an abrupt wrist reaction at the moment of finger-key impact. As the tonal intensity is increased this shock becomes more and more marked, and in *e*, and *f*, even in *d*, shows a curve similar to that shown in Fig. 77 for a rigid wrist.

Similar results were obtained when the contraction of the appropriate muscles was recorded. In forced arm-stroke, for example, the volar flexors of the wrist must contract in order to prevent the hand from bending back at the wrist when the keys are depressed. This contraction, however, is of no mechanical value during the part of the arm-stroke preceding key-depression. Accordingly, in a well-coördinated movement we should expect to find these muscles contracting at the moment of key-impact and not before. Fig. 40, in the chapter on Coördination, shows a record of such an arm-stroke. A chord was played *fortissimo*, preceded by a high arm-lift. The top line shows the beginning of the stroke, the middle line the key-depression and the bottom line the contraction of the flexor carpi radialis, the muscle we are here considering. The movement was typical of those used by trained pianists for loud chordal effects. In this figure the muscle is seen to contract at the moment that key-resistance is introduced, not before. Moreover, it is seen to relax a moment after key-depression, since but little pressure—the weight of the hand is quite sufficient—is needed to keep the piano key depressed. The muscle thus does what is mechanically necessary to attain the aim of the movement and not a bit more. Fig. 55, on the other hand, shows the same arm-movement made in an awkward, incoördinated manner, quite characteristic of untrained pupils and those of low coördinative ability.

Here the muscle that fixed the wrist is contracted a moment before the actual arm-descent begins. There is a very slight

additional contraction at the moment of key-impact, and a maintenance of this full contraction until the key is finally released. The contraction between the points *a* and *b*, and that between *c* and *d*, when compared with Fig. 40 shows the amount of wasted work. The only mechanical advantage is the contraction between *b* and *c*. In an incoördinated movement, therefore, the contraction of a muscle is timed incorrectly with regard to the movement as a whole, extending over a much longer period than necessary. Incoördination may involve not only the use of unnecessary muscles, but also the use at the wrong time of the necessary muscles. In both cases energy is wasted, and it is this waste that stamps the movement as incoördinated.

In all loud chordal work, therefore, the arm is fixed as, or immediately before the tone is produced. This rigidity is essential from a mechanical standpoint in order to attain the desired tonal intensity. The force on the descending arm acts downward.

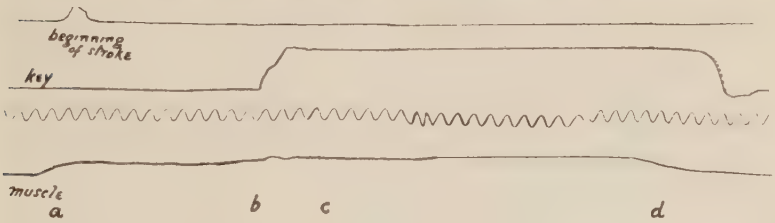

Fig. 55.

Any " give " in any part of the arm between this and the keyboard, will cause the force to bend the arm at such a point as soon as resistance is encountered. Force is consumed in bending ; hence is lost for tone-production. Because of this loss, we stiffen the wrist and the arch of the hand when maximal intensity is desired. This is another illustration of the incorrect assumption that all tone-production demands relaxation. We can speak of complete controlled relaxation only in the softest dynamic degrees, perhaps up to and including a *mezzo-piano*. Beyond this point, as the records show, rigidity increases, until for the extreme degrees of loudness, the arm is thrown against the keys practically as a rigid body.

Two types of records were made to prove this. In the first type nothing was said to the player about arm-condition and the instructions were merely to produce a tone of a given degree of intensity. The resulting arm-movement was then recorded and the degree of rigidity shown by the abrupt halt in the curves.

In the second type the player was told of the effect of stiffness

upon intensity and was then asked to attempt to produce *fortissimo* tones with a relaxed wrist and arm. Although quite loud effects were thus obtained, they were uniformly below the intensity levels obtained with rigidity and as soon as the player felt that he had produced a true *fortissimo* the recording lever showed stiffness of the wrist, although the immediate subsequent relaxation frequently deceived the player.

Coördination and Incoördination in Arm-Stroke.

In the time and force relationships between the arm-stroke and the muscular contraction necessary to offset key-resistance and hammer-impact, we have the true physiological basis of coördinated movement. In Fig. 40 the muscle fixing the wrist against over-extension (the flexor carpi-radialis) is shown contracting just before key-resistance is met, and relaxing immediately after key-depression. The movement was typical of the easy and natural movements of the trained pianist and represents, therefore, a well-coördinated movement. Contraction of the wrist flexors occurs just in time to overcome the key-resistance ; contraction before this time would be wasted energy since no resistance is present. The contraction ceases just after tone-production because sustained contraction would at that time again be useless on account of the absence of resistance. The definition of coördination given in Chapter IX does not permit a waste of energy.

If, now, we record the movements of a pupil lacking in coördination we get a result of which Fig. 55 is typical. There is little or no difference in the amount of rigidity present at the moment of tone-production—the difference is in the duration of contraction. The brevity of this, in coördination, has led to the conclusion that the tone is itself produced by a relaxed hand and arm, which, however, is not true. The teaching of the proper timing of the rigidity instead of its complete avoidance is the problem of pedagogy.

Effect of Tempo on Arm-Drop.

Since the two mechanical variables determining the final key-board force of the descending arm—assuming the mass to be a constant—are its velocity and the distance through which it moves, they will affect the speed and range of successive arm-movements. Tempo, thus, similar to intensity, will cause variations in the type of arm-movement used.

If the arm-drops succeed one another at a very slow tempo, the touch-form described in the preceding pages for the isolated arm-lift and controlled arm-drop will remain. As the tempo increases, and reaches a point where the time consumed in making

a complete arm-descent and ascent overlaps with the following descent, a change in the physiology of the movement must occur. The same mass must attain the same final force in less time. If the distance through which the arm moves is kept the same, the velocity of the arm will have to be increased. This, in turn, means an increase in the force, which is measured by the product of the mass and the acceleration. In order to keep the original force, therefore, the velocity would have to be reduced just before tone-production, by contraction of the appropriate inhibiting muscles—the antagonists to arm-descent. Mechanically this is so much wasted work. The greater velocity is needed in order to let the strokes follow at a sufficiently rapid tempo, and then this velocity must be reduced so as to keep the resulting tonal intensity the same. This would not only have to take place near the keyboard end of the stroke but likewise at the top of the stroke, where the direction of the arm changes from ascent to descent, for the velocity of ascent is likewise greater than before and hence requires a greater force to overcome it. This forced inhibition is not in keeping with a well-coördinated movement, which, as we have learned, is one with a minimum of wasted work. Accordingly, we do not find this touch form actually used.

In order to play a sequence of tones in rapid succession we do not increase the velocity and keep the range of slow movement. Instead we reduce the range and attain the increased velocity by a more forceful contraction of the appropriate muscles. This additional contraction gives the arm the desired velocity in less distance than before, and the shorter range of movement enables us to play the tones in more rapid succession.

This influence of tempo upon the range of pianistic movements may be seen by comparing any two figures recording the same movement with a difference in speed. As examples see Fig. 66, *c* and *d*, and Fig. 96.

It is quite characteristic of pupils possessing poor muscular coördination to execute a rapid movement at an enormous range and with an enormous expenditure of energy. This is shown in Fig. 96 for the simple tapping movement. I recall in this connection that a pupil with a very low coördination index, in her attempt to get speed into the tapping, lifted herself from the chair—she weighed about 130 pounds—and the entire body became rigid while she thumped with a force that drove the recording lever mercilessly against its limit of range. Of course, the speed was very sub-normal, so that the enormous expenditure of energy with its resultant early onset of fatigue was entirely useless, so far as the aim of the movement was concerned.

CHAPTER XIII

Lateral Arm-Movement

Lateral arm-movements, as a result of which the hand is moved along the keyboard, constitute the second fundamental class of arm-movements used in piano-playing. They are as important as, in some ways more important than the vertical arm-movements analysed in the preceding chapter. The purely horizontal phase of such movement has been described, and the sources of generation listed, in the discussion of horizontal movement. The lateral arm-movement with which we are here concerned is not a simple horizontal movement but combines with its horizontal displacement a varying amount of arm-lift and arm-drop. In reality, therefore, the movement is a combination of arm-drop, arm-lift, and lateral arm-shift, and the ratio of vertical to horizontal distance varies over a wide range. The analysis, therefore, will be concerned with both aspects; the vertical and the horizontal.

In order to transfer the hand from one part of the key-board to another in the least time and with the least effort, at the same time avoiding the striking of intermediate keys, the hand must be lifted from the first key, transferred to a point above the other key, and then lowered. According to such a division the movement would be made as shown in Fig. 56 A. This is the plan followed by the doctrine of "preparation" which demands that the moving part be placed over the next key to be played as quickly as possible, and held there stationary until the time to play. I perhaps exaggerate this somewhat in Fig. 56 A, because in many instances of preparation, the initial lift is not insisted upon, but merely the immediate transfer of the moving part over its next key. Such a movement may be more accurately represented as in Fig. 56 B. In these and in subsequent figures in this chapter the curves are shown as they would appear to the player if the eye were on a level with the keyboard. The reader, therefore, is supposed to be facing the keyboard, as a player would see it, with the keyboard raised to the level of the eye. This does away with the fore-shortening of the vertical displacements if the eye were above the keyboard level. Such a movement divides itself into three parts: a muscular contraction starting the hand along *ac*; a compensatory contraction

to bring it to a stop at *c*; a third contraction for the movement *cd*. The force *ac* is working at maximal efficiency, since it transfers the hand over the key in as short a distance as possible. The inhibition and poising at *c* is wasted work since it does not affect

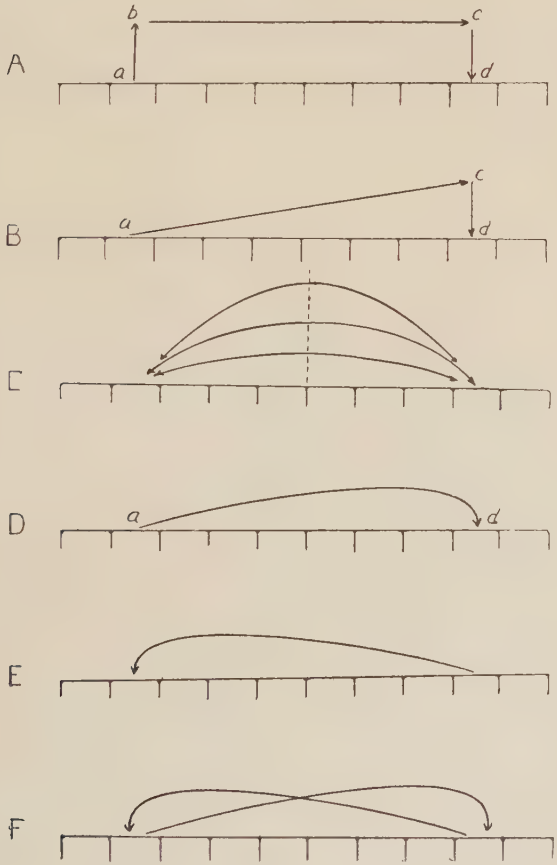

Fig. 56.

tone-production. The hand in passing from *a* to *c* already has a velocity sufficient to produce the desired tone, but acting in an inefficient direction. A change of direction is needed for adequate tone-product on.

The movements of preparation, shown in Fig. 56, A, B, demand

that this velocity be reduced to zero, and then be generated again. The necessary change of direction has been secured in a mechanically wasteful manner. Moreover, such a movement, mechanically considered—and to a certain extent also physiologically considered—is in truth two movements : a lateral arm-transfer and a vertical arm-descent. The mechanical properties of one part do not affect the second part because a period of rest intervenes, even though the arm be poised over the keys. The movement of Fig. 56 B, therefore, is mechanically wasteful and physiologically incoördinated since it does not attain its aim with a minimum expenditure of energy.

The awkwardness in this movement is the manner in which the change of direction is secured, which violates all principles of smooth mechanical motion. The alternative is to secure the change of direction without a loss of velocity. This may be done by substituting a curvilinear for the rectilinear motion, and, given in its simplest form, results in a curve such as that in Fig. 56 C. Here the change of direction is in infinitesimal increments, and shows the action of a constant force. This we infer from the parabolic nature of the curve. The velocity may remain unaltered, and all incoördination resulting from the shock of an abrupt stop or change, is eliminated. But this gain has been accompanied by a loss in the efficiency of the direction in which the final force acts. It is measurable by the angles made by the two sets of arrows. The key-movement being vertical, maximum efficiency of the force demands that it, too, act in a descending vertical. A gain in direction may be secured, without loss in velocity, by raising the height of the curve, shown by the dotted line of Fig. 56 C. But this gain is again accompanied by a loss, this time in the needlessly wide arc, the hand traversing a considerably greater range than that needed for the desired tone-production. And since coördinated movement does not allow excess energy, the highest curve of Fig. 56 is still not the most effective way of securing the desired result.

We get this efficiency by keeping the curve relatively low and shifting the direction change to one side as in Fig. 56 D. Here the hand reaches the key in a vertical direction, there are no angles to interfere with velocity, and there is no excess arm or hand lift. The type of motion shown, therefore, fulfills all the requirements of coördinated movement.

The reverse movement may be readily inferred. Here the geometric and mechanical phases are reversed. Accordingly, the movement will be made about as in Fig. 56 E.

The hand, therefore, would not traverse the same path for its

return movement as it would for the first part of the movement. And this condition would hold for all similar movements. The leap of an octave, back and forth, for example, is not a single arc of a circle, or two coinciding arcs, with only the direction of movement reversed, but a different arc. For the curves are not symmetrical with respect to an axis midway between the end-points. This asymmetry, contrary to popular belief, is an integral part of all piano technique, as we shall find later. Finger-lift and finger-drop, arm-ascent and arm-descent, ascending and descending scales and arpeggios are not mere opposites, but physiologically different movements. The muscular action is not simply reversed, it changes in kind.

If we combine the two curves, D and E, shown in Fig. 56, we get F. The only incoördinated phase revealed by this curve is in the sharp points at the key-surface. These points, however, are partly determined by the shock of the key against the key-bed. The resistance introduced is abrupt, and external; consequently quite different from that shown at *c* in Fig. 56 B, where the change

Fig. 57.

is entirely muscular. No muscular coördination can entirely overcome this shock at the points of key-contact, without sacrificing tone-production. However, this undesirable feature of the movement can be reduced somewhat by rounding off the point slightly.

The curve then takes the form shown in Fig. 57.

From theoretical, mechanical, and physiological standpoints, therefore, this is the typical curve we should expect to find when we record lateral arm-movements in opposite directions.

Records of lateral arm-movements under normal playing conditions may be made in several ways. By appropriately arranging a pantograph, attaching the tracing point to the wrist in such a way as to avoid all play and yet not restrict the movement, and letting the recording point trace its motion on a smoked or plain paper surface, the lateral arm-movement, on a reduced scale, will be accurately recorded, Fig. 58. This device demands some adjustment of detail before it will operate satisfactorily. The substitution of a universal joint for the usual pivot will allow for a slight motion in planes other than the recording plane and will thus remove the constraint placed upon the player if the instrument

operates in only one plane. To allow for the deviations thus permitted, it is necessary to have the recording surface reënforced by sensitive springs, which will keep the surface pressed against the recording point as it deviates from the vertical plane. Finally, the attachment of the lever to the arm must be firm, yet not interfering with movement. I have found the use of a wide heavy rubber band, comfortably tight around the arm, and sufficiently strong to overcome the resistance of the instrument, quite useful and satisfactory. A number of small, thin elastic bands, attached in various directions and loops will hold the lever-end firmly against the arm-band. In fact, such an arrangement makes a very satisfactory substitute for a universal joint. It is serviceable for measuring all displacements in a vertical plane, parallel to the line of the keyboard.

A simple form of such motion is that made by the hand in skipping from one octave to another and back again. In order to avoid finger action, octaves instead of single keys were played, and the interval used was also an octave. The speed was moderate, intensity also. A typical form of curve obtained is that of Fig. 59*a*.

When this is compared with the curve of Fig. 57 it will be found to agree in all phases, as they have been analysed in the preceding paragraphs. We find the double-loop, the rounded corners and flatted arcs. The hand is not lifted unnecessarily high, the curves are not symmetrical with respect to a midway vertical axis, and angles have been eliminated.

In order to eliminate all doubt as to whether this curve could be affected by the method of recording used, I employed a much better and more refined method for most of the records used in this and subsequent chapters. The apparatus consisted of a tiny electric bulb and socket, about one-eighth inch thick and three-quarters inch long, to which very fine flexible wires were attached. Current was furnished by dry cells, and an appropriate rheostat made control of the intensity of the light possible. The electric bulb was then firmly attached to the part of the finger, hand, or arm, the movements of which were to be recorded. These movements were then photographed, the intensity of the light being ample to affect very clearly the photographic plate. Needless to say, the room itself was in very subdued light. The weight of the light and socket was about one-eighth of an ounce ; its attachment to any part of the arm thus required but little force to insure firmness. Moreover, the pianists whose movements were recorded admitted that its attachment in no way interfered with the naturalness or freedom of the movement.

Fig. 58. The Pantograph method for recording Lateral Arm-transfer.

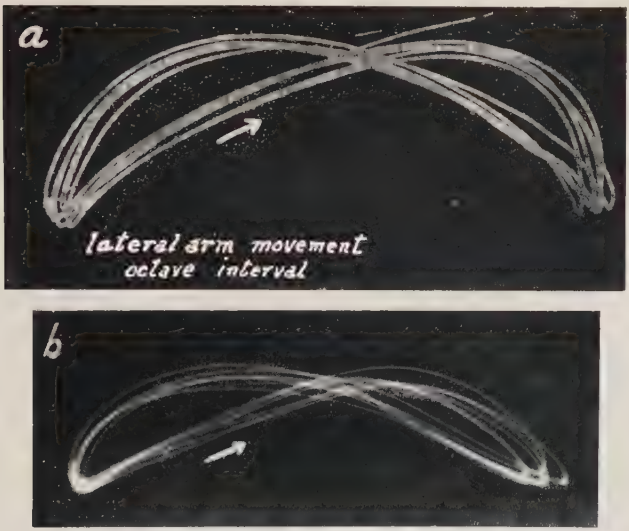

Fig. 59. *a*. Pantograph record of repeated octave leaps; *b*, photographic record of a similar movement.

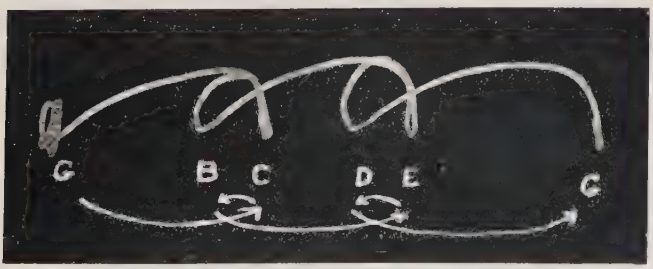

Fig. 61. Pantograph record of alternating ascending fourths and descending seconds: G—C—B—E—D—G—

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The curve for a lateral shift of a twelfth, at moderately fast speed and moderate intensity, with the light fastened behind the hand-knuckle of the third finger, is shown in Fig. 59*b* and agrees very closely with that obtained by the first recording method, Fig. 59*a*. Since there could be no "play" in the photographic recording, the form of curves shown in Fig. 59 are true pictures of the path traversed by the hand in such a movement.

The form of the curve moreover, helps us to analyse the operation of the underlying mechanical forces. In the chapter on Coördination and Incoördination I pointed out the fact that in lateral arm-shifts of sufficient speed and amplitude the arm is "thrown" by a maximal initial contraction, and thereafter traverses a part of its path as a relatively free body. The path traversed by a free body thrown into the air is a parabola, a curve symmetrical to an axis passing through its vertex and focus. When the arm is thrown sidewise by another person, or when it is similarly thrown by appropriate maximal muscular contraction at the beginning

Fig. 60.

of the stroke (this latter method demands careful practice on the part of the experimenter), it will describe a curve typified by those shown in Fig. 56 C. These are parabolical, symmetrical to the axis represented by the dotted line. That is to say, if the movement of the arm be unarrested, gravity will act to guide the hand in a parabolic curve. The difference between this curve and that actually made in playing the interval in question may then be seen by superimposing a parabola on one of the curves of Fig. 59, so that the initial (left side) parts of the curves coincide. The result is seen in Fig. 60.

The part of the curve between *a* and *b* may be considered the part in which the hand travels as a free body. If this freedom continued the hand would move in the direction of the dotted line *bd*. The fact that the lateral motion is already stopped at *c* shows that contraction of the humerus rotators and the arm adductors is guiding the hand to its goal at *c*. There has accordingly been more initial contraction than that actually necessary to reach *c*, but the gain has been in greater velocity and in the more advantageous

direction in which the hand finally strikes *c*. In the chapter on coördination, records showing these muscular contractions are given (Figs. 34, 40); here we see the same contractions reflected in the geometric aspect of the curve itself.

From the preceding analysis and records we can determine in advance the type of curve which will result when combinations of lateral shifts occur, in which the range of each step varies. A progression from G up to C, back to B, up to E, back to D, up to G, is an example. An ascending fourth is followed by a descending second. Since the amplitude of the curve does not increase with the range (see page 162), the return from the high points will more nearly coincide with the ascent itself. Fig. 61 illustrates the movement of the hand in an octave progression on the keys mentioned. The characteristic loop on the right hand side is absent, because the hand returns at a higher angle from C to B than that present when it passes from B to E. If the distances had been reversed into an ascending second and a descending fourth, the loop would be reversed.

The mechanical advantage of these curve-forms is a gain in direction of force with minimal distance traversed. The curves, in general contour, are not unlike the preparation curve of Fig. 56 B, the difference being in the rounding off of the point *c*. It is possible that the value of teaching preparation in the acquisition of new movements is in this similarity, in spite of the obvious waste of such a movement as that typified in the preparation curve. The question is primarily a psychological one, the answer to which I prefer to withhold until I have secured sufficient data on practice effects. At any rate a preliminary investigation, in which the pupils were taught to move the arm from the beginning in the form of Fig. 57 instead of Fig. 56 B, has produced very gratifying results, and seems to indicate that a knowledge of the curve-forms used in actual playing is of more than theoretical interest and value.

Dynamic Effects.

The movements thus far considered have been analysed without considering intensity and speed. In actual piano-playing, however, the same distance must be traversed with various tonal intensities as aim, and at various speeds.

Variations in intensity may affect the curve of motion in several ways, by increasing the angularity when descent begins (as in B, Fig. 56, and Fig. 60), or by increasing the amplitude (height) of the curve as a whole (as in Fig. 56 C). An increase in angularity would reintroduce the sudden shift of forces, the extreme being

Fig. 62. Pantograph records of repeated lateral arm-movements, showing the effect of tonal intensity upon amplitude of curves.

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Fig. 63. Pantograph records of repeated lateral movements (interval: a twelfth) showing effect of intensity upon amplitude of curves.

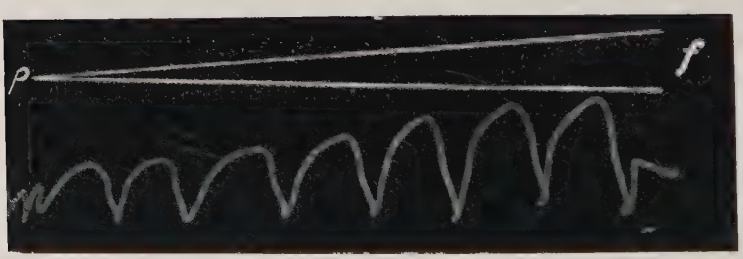

Fig. 64. Ascending diatonic octaves, showing effect of intensity upon height of curve.

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that of Fig. 56 B. This, in turn, demands the rigidity which is a necessary part of all loud tonal effects. It would involve greater inhibition and a proportionately greater renewal of speed after the turn. The increase in amplitude of the curve as a whole, on the other hand, introduces none of these difficulties (see Fig. 62). The direction of key attack remains much the same, the curvilinear nature of the curve reflects maximum mechanical efficiency and the greater distance traversed means greater velocity. Since the mass of the moving part is the same as before, this results in greater force at the key-end of the movement, hence produces a louder tone.

Fig. 63 also shows the effect of intensity or dynamic variations upon the lateral arm-movement. The interval represents an octave leap, *pp*, and the same leap *ff*. The angularity of the curve does not increase as we increase the intensity. Instead, the amplitude of the curve increases, this increase being shown by the greater height of the curve for loud tones when compared with that for soft tones. The curvilinear nature of the movement and the resulting mechanical advantages are thus retained, with the necessary gain in velocity needed to produce the louder tone.

Steady variations in dynamics are illustrated by the *crescendo* and the *decrescendo* or *diminuendo*. A typical pantograph record of a crescendo made for a diatonic octave progression through one octave is given in Fig. 64. Two features of the movement should be noted ; the nature of each curve remains unaltered in any fundamental aspect, and the crescendo is directly reflected in the increase in amplitude of the curve. From the nature of each arc the speed may be inferred as moderately great. (This is explained in detail under Agogic Effects.) Thus intensity does not affect the nature of the curve but only its amplitude. The point recorded in Figs. 62, 63, 64 was the centre of the hand.

A check was, of course, made with the photographic method, which produced identical results. It is interesting to note, in this connection, that in two instances the players were absolutely sure that the crescendo was made without lifting the hand a bit higher, the increase in tonal-intensity being produced by using greater force with the same amplitude. Yet the photographs of both movements showed the usual increase in amplitude. I cite this to prove again the danger of relying upon the opinion of even first-rate pianists in an analysis of movement. Introspection usually alters the physiological response and the normal speed of the movements we are considering is too great to be analysed by the unaided eye. The graphic method alone is here dependable.

Agogic Effects.

The effects of variations in the speed of the movement are more pronounced. In a very slow movement, let us say one requiring two seconds for each arm-shift, the need for a "leap" as generally understood, does not exist. The movement may be made in two ways: by a steady, extremely slow, arm-movement, using the curve-form illustrated in the preceding figures; or by a somewhat more rapid movement, which brings the hand over the desired key, followed by a vertical descent. This is the method of preparation, it is true, but not exactly in the sense described on page 160. A steady arced movement would demand a force acting through a considerable time in order to overcome the effects of gravity. More work would be done in that case, than would be done in a more rapid movement. If the hand be moved close to the keyboard until it is approximately over the key to be played, and be then lifted, we save the lift during the transfer of the hand. The

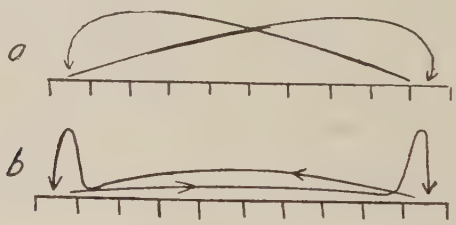

Fig. 65.

rate at which the key-depressions follow one another is sufficiently slow to permit the separate lift at the end of the stroke without mechanical waste or interference. The two types of curve are represented in Fig. 65.

From a mechanical standpoint *b* is the more advantageous movement, because it permits a greater part of the weight of the arm to be carried by the shoulder socket; and from a physiological standpoint it is also the better coördinated movement.

For these reasons we find it in the actual records and photographs made of lateral arm-movement under normal playing conditions, Fig. 66, in which the interval was a twelfth; *a*, duration of each stroke two seconds; *b*, one and one-half seconds; *c*, one second; *d*, approximately one-third second. At *a* the hand transfer was purely horizontal in three of the strokes. (The high curves are explained later.) Upon reaching its lateral goal, the hand was then lifted in order to prepare the ensuing descent. This accounts

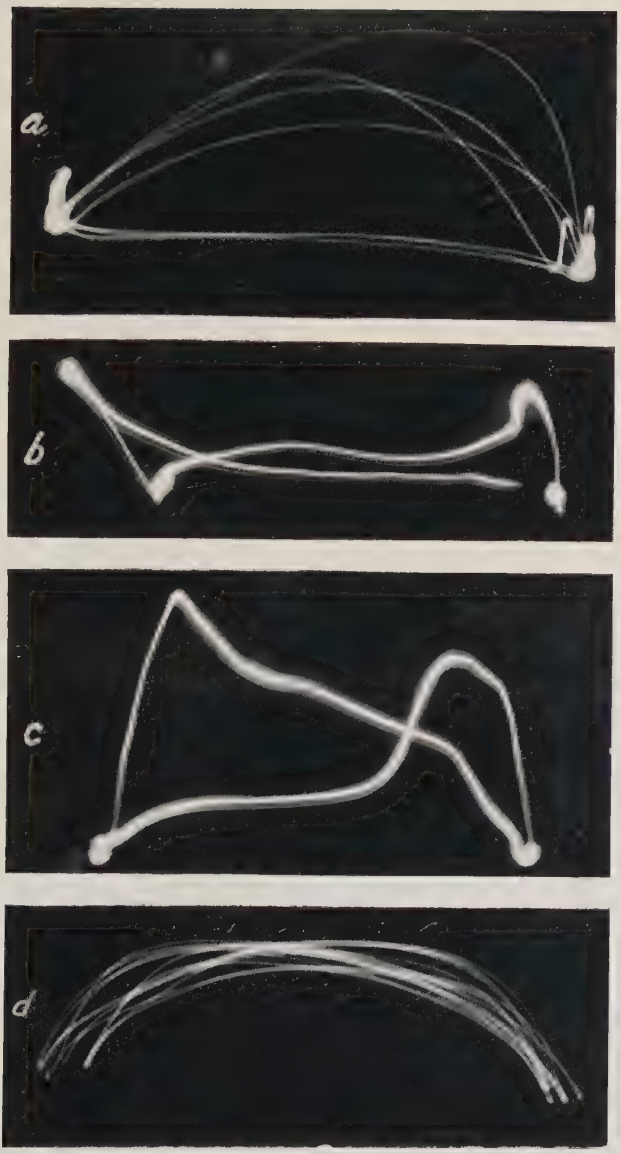

Fig. 66. Photographs of repeated lateral arm-movements, showing effect of tempo upon the form of curves : *a*, very slow ; *d*, very fast. (See Fig. 67.)

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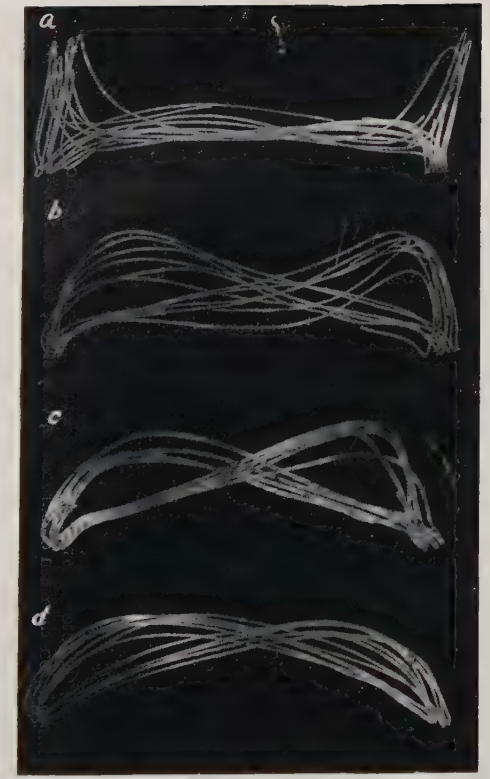

Fig. 67. Pantograph records, lateral arm-transfer, showing effect of tempo. (See Plate XII.)

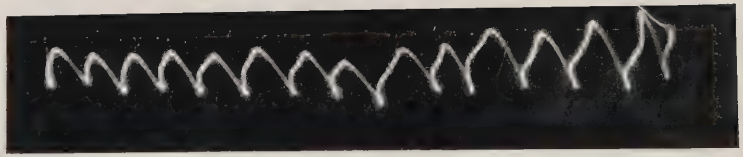

Fig. 68. Effect of *crescendo* and *ritard* upon form of curve. Ascending diatonic octaves; read from left to right.

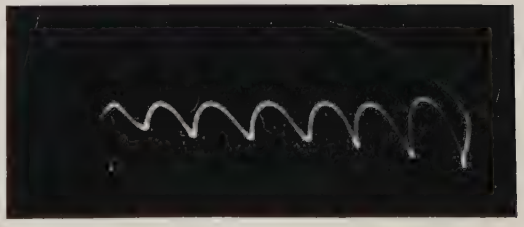

Fig. 69. Effect of *crescendo, without ritard,* upon form of curve. Ascending diatonic octaves.

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for the short towers at both ends. At the right hand side one curve at least, being slightly non-coincident with the others shows very clearly the separate rise at the end of the stroke. At *b* the speed was slightly faster but the horizontal transfer and the end-lift are marked. The same applies to *c*, although here, in the shift from high to low tones the horizontal aspect has been lost in the immediate rise of the curve. A small remnant of the end-lift remains near the upper left hand corner. Finally, when the speed is considerably increased beyond this point (*d*) we get the typical lateral curve with which we are already familiar.

The high curves in *a* demand explanation. This is a typical instance of wasted motion. The arm was excessively lifted, transferred, dropped to key-level, and then lifted a second time in order to prepare for the upper descent. The entire first lift was, therefore, wasted work. The motion was used because a previous conversation caused the pianist who made this record to concentrate on the arm-movement itself. Later records, made unobserved, that is to say, under normal playing conditions, showed complete absence of these high curves. It should be pointed out, moreover, that the high curves all occurred with an ascending interval. This is an illustration of a fact which we shall discuss repeatedly later, namely, that opposite movements so far as the keyboard alone is concerned are not necessarily or usually opposite muscular movements. The forms here given, although they are representative of individuals, are at the same time typical in their general contours, as many other records prove. In Fig. 67 a similar series of records, made by the pantograph method, is shown. The transition from the double movement to the single, as the speed of the movement is increased (from *a* to *d*) is more nicely graded in this series than in that shown in Fig. 66. The second series is given to serve as a check on the first. It proves that the typical nature of speed effects is independent both of the individual and of the method of recording.

Steady variations in speed are reflected musically in the *accelerando* and the *ritard.* If the arm-mass remain constant, an *accelerando* will demand an increase in velocity, and, if the tonal intensity be kept constant, an inhibition of this velocity immediately before tone-production. By reducing the mass of the moving part a gain in velocity may be secured with less expenditure of energy. In the lateral movements we are here considering, the range of the movement, an octave or a twelfth, is too great to permit substitution of a smaller unit than the arm, so that the effects of the *accelerando* will be reflected in the nature of the curve,

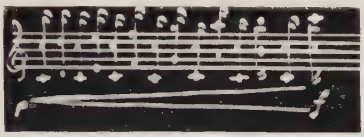
as shown in Figs. 66, 67. If, on the other hand, we vary both speed and intensity, as in a *calando*, the agogic aspect demands varying velocity, and the dynamic aspect also. The effects of each, alone, have been given: the one keeps the angle of incidence between finger and key as effective as possible, the other minimizes the resistance of gravity. We may logically expect, therefore, to find variations in both the amplitude and the nature of the curve when we record a movement combining the crescendo and the ritard. Reading Fig. 68, from left to right, which represents a diatonic octave passage with crescendo and ritard, we note that the curve changes gradually from the single arc to the lateral shift plus end-lift characteristic of slow movements. At the same time the increase in amplitude reflects the crescendo phase. (The depression in the middle was an unintentional shift in the hand-position, remarked by the player after the passage was played.) And for the same reason, only the amplitude should change if the crescendo be made with uniform speed. This gives the typical curve shown in Fig. 69 which is additionally valuable because the pianist making the record insisted that he made his crescendos without any increase in the height of arm-lift. (The partial distortion of the curves results from the angle at which the movement was photographed.)

Range Effects.

We have finally to consider the effects which variations in the lateral range have on the other phases of the movement. Such variations are, unfortunately, inseparably linked with variations in speed. If, for example, I move my arm through a distance of one foot, then through two feet, when the time is constant the speed is doubled; when the speed is constant the time is doubled. Accordingly, the preceding analyses of dynamic and agogic variations furnish the clue to the effects of range. Fig. 70 shows the fore-arm movement for the passage played: C–D–C–E–C–F–C–G–C–A–C–B–C–C. The point photographed was, as before, the centre of the hand, at the third finger knuckle. The speed, even had it not been recorded at the time of the playing, could readily be inferred from the nature of the curve, which is that of a moderately rapid movement. Since the notes played were of equal value the velocity of the hand increased with an increase in the size of the pitch or keyboard interval.

The amplitude of the curves does not increase as the distance increases. The hand is lifted just as high to get from C to the adjoining D as it is to get from C to its octave. As the distance

Fig. 70. Photograph of hand-movement in the octave figure : C—D—C—E—C—F—C—G—C—A—C—B—C—C. Intensity uniform. Note flattening of curve with increase of interval.



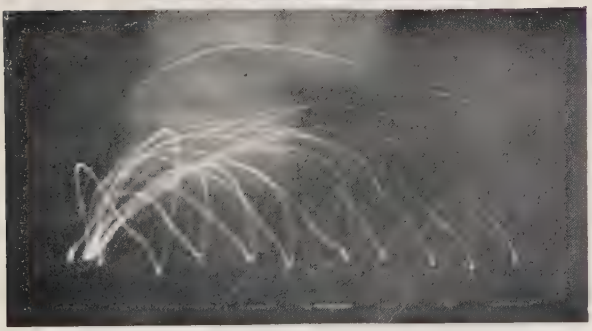


Fig. 71. Same as Fig. 70 with a *crescendo* added. Note increase in height (amplitude) of curve. (Compare with Figs. 62, 63, 64 and 69.)

Fig. 73. Displacement of curve-apex as a result of tone-accentuation. (Compare with Fig. 59, *b*.)

[*To face p.* 170

increases the curve grows flatter, and the ratio of vertical to horizontal displacement grows smaller. We may conclude, therefore, that with intensity constant, the lift of the hand is independent of the lateral distance. It remains constant for any one degree of intensity. The increase in arm-velocity which necessarily accompanies an increase in interval would normally produce a louder tone. This is counteracted by the angle at which the force acts, and by muscular inhibition ; the angle varying from approximately 80° for the diatonic step to 45° for the octave.

When intensity is increased, that is to say, when a crescendo is made in playing the passage in question we get the curve of Fig. 71 which shows an increase in amplitude as the interval is increased. As a result the hand reaches each key, regardless of the distance involved, in an approximate vertical direction. The greater distance

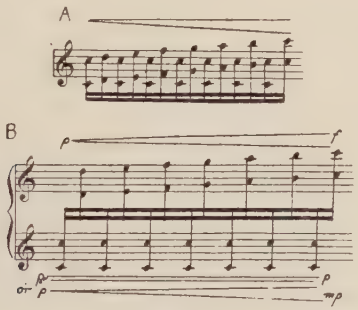



Fig. 72.

travelled results in a greater hand velocity, which causes the crescendo. In this particular record the crescendo applied primarily to the upper tones, those forming the scale. The repeated C was kept at a more uniform intensity. As a result we have a marked raising of the peak of the curves to the right and no similar displacement for the return strokes to the left. This manner of making a crescendo in a passage like the given one is more widely used than is generally believed. The printed page marks the crescendo as extending uniformly over high and low tones as at A, Fig. 72, but in reality it is often played, for artistic reasons resulting from the melodic relationship of the upper scale-line, as at B. The curve of Fig. 71 shows some of this dynamic relationship, though in a slightly less pronounced form, and accounts for the lower curves at the left-hand (middle C) side of the passage. That is to say,

the range of crescendo on the scale line exceeds that on the repeated tone-line. Similar passages in piano literature abound: the accompaniment figure in Raff's La Fileuse, the left hand passage in Chopin's Etude, Op. 10, No. 4, shortly before the end and the right hand in the same opus, No. 3, may be mentioned.

Effect of Intensity upon Accuracy.

In the chapter on coördination intensity was shown to depend upon the spread of muscular contraction: the production of a loud tone involved a larger muscular field than the similar production of a soft tone. In other words, the mass is greater in one case than in the other. But the property of inertia makes a large mass unwieldy wherever rapid changes of direction in the movement are necessary. And we actually find such unwieldiness reflected in a lack of accuracy when we record for comparison differences in intensity. These are demanded, for example, in passages involving accentuation of certain tones while the arm is shifting its position rapidly, Liszt's Campanella, or the end of Schumann's C major Fantasia are instances. The difficulty, in its simplest form, is represented by rapidly repeated octave leaps, with all the lower or all the upper tones, but not both, accented. The result is given in Fig. 73 in which the lower tone at *a* was the accented tone. We note, of course, the typical increase in amplitude with an increase in intensity, which throws the apex of the curves for the descending arm to the point indicated by the arrow, while no symmetrical point exists for *b*. But we note also a convergence of the lines of motion as we approach or leave *b*, and a divergence on the side of *a*. Since the position of both keys was equally accurately fixed, this divergence cannot be mechanically desirable, and represents an inaccuracy in the movement. A study of other figures where uniformity of speed makes the comparison possible (Fig. 96) will show a similar lack of accurate control. The difficulty thus becomes general, and since it is absent when the intensity difference is excluded, we may safely consider it a result of intensity. It points, once again, to the fundamental physiological association between speed (including accuracy) and lightness. *And, conversely, if accuracy be the aim in learning a passage that involves leaps and speed, the lightest possible practice will be advisable.* Such passages are proverbially difficult, hence the admonition not to "force" in their performance has a real physiological and mechanical basis.

Spring-Release.

In works on piano technique one frequently meets the conception that the hand and arm, in leaving a key rapidly, do so with a spring,

a sort of " kick-off ", similar to the kick of a gun. The conception is erroneous, though the error can be explained. Very frequently the abrupt leaving of a key for an extended leap has been preceded by an equally abrupt leap to the key. The duration of key-depression is so short and abrupt, that a certain amount of force is consumed in pressure against the key-bed. This readily gives the feeling of a " kick-off " from the key. A second factor leading to the belief of a spring-release, is the initial finger thrust or lift which we shall study later, under the effect of intensity variations upon the finger-stroke.

The truth of the matter may be learned by recording the muscular contraction and the path of hand or arm-movement. If a kick-off takes place, there must be a force acting in a direction opposite to that in which the hand moves. Therefore, if the hand be placed upon a sensitive balance and be abruptly moved in the direction

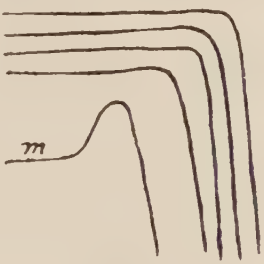


Fig. 74.

taken in a lateral keyboard leap, the kick-off will result in a momentary depression of the balance, showing the downward acting force. Absence of this depression means that *Abstoss* (the German term is here superior to the English) is not present. Fig. 74 shows four records of the needle of the balance at various intensities, to which I have added the curve that would result if a " kick-off " were present. There is no deflection in any line recorded. That holds for any degree of intensity, indicated by the various intensities shown. As the hand leaves the surface of the balance there is an immediate release of pressure, and not a sign of an increase, which is indispensable if a " kick-off " had been present.

Furthermore, if the hand were thrown from the key in such a manner, with a " kick-off ", the contraction of the muscle would be affected ; in fact it would be partly superfluous because some of the force would be gained by the assumed elasticity of the key.

But we find precisely the same contraction of the muscle (Fig. 75) whether the hand be started in mid-air or from the key-surface. In this figure *a* shows the contraction of the *pectoralis major* when the arm is transferred laterally through several octaves from key

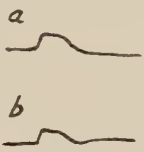


Fig. 75.

to key ; *b*, the same movement started in mid-air. The contraction of the muscle is the same in both instances.

Finally, in such a start, if a kick-off were used the hand would first move a short distance in a direction opposite to that desired, for in starting from mid-air there would be no key-bed resistance to oppose this downward acting force, hence its effect would be

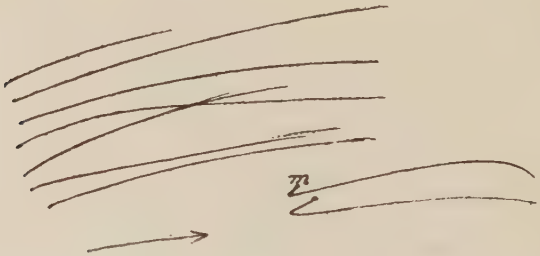


Fig. 76.

shown by movement in the direction of the force. Fig. 76 records directly the movements of the arm from a point of rest in mid-air. The lines start immediately in the direction of movement and do not show any signs of an opposite force. At *m* are shown two curves to illustrate the effect of the opposite force, if it were present.

PART III

THE TOUCH-FORMS OF PIANO TECHNIQUE

CHAPTER XIV

Arm-Legato

This type of movement characterizes the playing of most slow cantabile passages requiring at least a moderate degree of tonal intensity. The arm is alternately raised and lowered while the finger-tip remains in contact with the piano-key. The touch is roughly comparable to the controlled arm-drop already discussed, the chief difference being in the actual distance through which the finger-tip itself moves. In the arm drop and lift, the hand finally leaves the keyboard. In the arm-legato the lift of the hand must cease, when the hand reaches a vertical position, otherwise the legato will be destroyed.

The primary value of such a touch-form, apart from its legato property, is in the control possible, and in the reduction of the percussive noises. It seeks to combine the advantages of the arm-drop with those of the non-percussive touch. A so-called "singing-tone", the usual aim of the arm legato, is a tone of at least moderate intensity. This demands sufficient key-speed, and this, in turn, sufficient muscular force. The distance through which the key moves before tone-production is less than three-eighths of an inch. The attainment of the desired speed within this distance demands a fairly quick and considerable application of force. The weak finger muscles are normally not adapted to this work. Therefore, the weight of the arm, and the contraction of the arm-depressing muscles are brought into play. The greater distance through which the arm moves gives a better control of the dynamics, and the non-percussiveness between key and finger-tip eliminates the interference of "shock". Experiment has proved first that the range of movement is, within certain limits, one determinant of the control of the movement: the greater the range, other things equal, the better the control. Secondly, that any percussiveness produces "shock" which in turn interferes seriously with kinesthetic judgments, particularly where, as here, fine discriminations are involved.[1] One must remember, however, that range ceases to function as a determinant of control when the speed becomes great.

[1] O. Ortmann: "Weight Discrimination as a Measure of Technical Skill in Piano-Playing," *Jl. Comp. Psych.*, vol. iii, No. 1.

The amount of arm-weight introduced into the tone-production varies from zero to the greater part of the weight of the whole arm. It can never reach the entire arm-weight on account of the shoulder attachments. (See Chapter XI, on Weight-Transfer.) The contraction of the appropriate arm-muscles may be used to any degree, so that we can pass from the finger-stroke to the final full-arm stroke through many degrees of intermediacy. The hand, the fore-arm, or the whole arm, for example, may be the playing unit. Each will affect the key-movement in a particular way. Some typical differences are found in the curves of Fig. 117. When the finger stroke alone is used, unsupported or unaided by arm-weight, the movement of the finger takes place as at *a*. When combined with hand-weight and some muscular contraction in the fore-arm the curve at *b* results. The normal cantabile full-arm tone is shown at *c*, and at *d*, an exaggerated full-arm descent. As we pass from *a* to *d* we note a gradual elimination of the break in finger-descent. This abrupt retardation, shown by the horizontal break at the arrow-point, in the descent of the line, is most marked at *a*, because, with only the finger as the playing-unit, the ratio between key-resistance and playing-weight is relatively large, and when the key is touched a noticeable retardation in the finger-descent is the result. The retardation is less but still readily discerned in the curve for hand-weight at *b* whereas in the curves for full-arm it has been practically eliminated. Since any abrupt break in curves recorded as were these, represents an element of impact or " shock ", the desirability of using a more massive tone-producing body than the finger, in any slow, sustained tone-production is evident. The details of the proper distribution of forces are given in the chapter on Finger-Stroke.

Wrist Movement in Arm-Legato.

At the same time the relatively slow tempo and the moderate intensity of tone desired permit the use of a partially relaxed arm. A conspicuous feature of this relaxation is the ease and grace of the movement of the wrist region. (See especially Fig. 78.) Fig. 77*a* shows the descent of the wrist for well coördinated relaxed arm-descents. For the sake of comparison two curves *b* made with a rigid wrist are likewise given in the figure. The relaxed arm continues on its descent uninterrupted at any specific point by the sudden action of key-resistance. By proper adjustment between finger-speed and arm-speed, the percussiveness is completely eliminated. With the rigid wrist, however, the shock of finger-key impact is directly transferred to the wrist ; and this, being

fixed, comes to an abrupt stop. The relaxed arm, therefore, eliminates the element of shock from this touch-form and conversely stated, the elimination of shock or impact repulsion demands *pari passu*, a relaxed muscular condition.

A comparison of the upper parts of both curves of Fig. 77, up to the point at which key-resistance is met, shows marked similarity. From this we may infer that the stiffness of the wrist does not materially affect the muscles in the shoulder, which control the movement of the upper arm. The descent of the arm may yet take place freely although a part of the muscular system within the arm is in a state of hyper-tension. Such a coördination, for example,

Fig. 77.

enables us to strike a forcible blow with accurate aim. The point is important technically because it shows that not all joints in a movement need be relaxed. So long as the joint in which movement actually takes place (the angle made by the bones must change if there is movement) is relaxed, and the fixation of other joints does not play over into the relaxed joint, this fixation will not interfere with the accuracy of the movement.

Failure to allow for this combination is responsible for the popular belief that in tone-production with a fully relaxed arm, finger and wrist joints are likewise fully relaxed. That is not true, the finger-joints are most decidedly not relaxed, and the wrist-joint only partially so. We are primarily conscious of relaxation because

in any movement our sensations come chiefly from the joint at which the greatest motion takes place, in this case the shoulder. But this feeling of relaxation is not a true index of the physiological mechanics underlying the movement. All joints between the point at which the greatest part of the motion occurs and the finger-tip, must be fixed sufficiently to transmit the desired force, without loss, to the piano-key. For *piano* degrees the fixation is slight, for *forte* degrees, it is considerable. The mechanical principle involved is that of a compound lever. (For additional illustration of the ease and grace of wrist movement in the arm-cantabile see Fig. 78.)

Weight Distribution.

Closely connected with the problem of arm-movement in the arm-legato touch is the distribution of the arm-weight during the successive key-depressions. Most textbooks speak of and lay special stress upon a transfer of weight : the shifting of the weight from one finger to the next, with no withdrawal between. The advocates of the " Rollbewegung " go a step further and demand

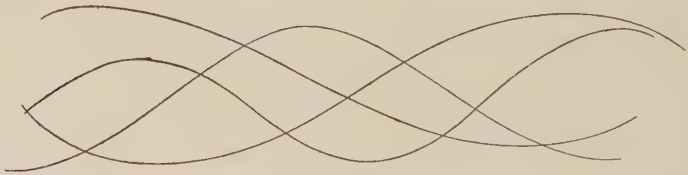


Fig. 78.

the rolling of the arm-weight from one key to the next in a manner similar to that of a rolling wheel, in which the spokes carry the weight in turn.

Once again this conception is illusory and at variance with the mechanical principles underlying the movement. With the arm relaxed there can be very little weight transfer during arm-ascent, and arm-ascent is a necessary phase of the movement we are now considering. As the arm is lifted its free weight is obviously withdrawn from the keys. A weight of a few ounces is all that is needed to keep the piano-key depressed and this weight is but a small part of full arm-weight. Hence the depressed key may give the impression of carrying arm-weight when actually it is carrying a minimal amount, the arm-ascent usually having removed more than ninety-five per cent thereof.

The rate at which the withdrawal of weight takes place varies primarily with the speed and with the rigidity or relaxation of arm-ascent. A rigid arm will require but a very minute motion at

the shoulder to lift the finger-tip entirely from the key, and hence the withdrawal of weight and the cessation of tone take place very rapidly. The arm is, in such a case, a simple lever with the fulcrum at the shoulder.

If, on the other hand, the arm is partially relaxed, gravity will cause the hand to remain unlifted until the upper arm has been lifted. Weight-release will consequently be much slower, and will at the same time be under better control. The inference from this graduality, that the tone is likewise gradually stopped, is erroneous. The cessation of tone results from the fall of the damper upon the string and the nature of this mechanism in the piano precludes any gradual stopping of the vibrations of the string. The mechanical advantage of the slow key-release is in the reduction of the noise-elements (the thud of the returning action-parts) and in the better muscular control.

The transfer of the force of full weight during arm-ascent is, of course, physiologically possible. We can even increase key-pressure during arm-ascent, but certainly not by a relaxed arm. And for what purpose ? It does not influence the tone that has sounded nor does it help the preparation of the next tone. The distribution of forces during arm-lift, in relaxation, make a maintenance of full weight or an increase thereof at the finger-tip impossible. The only muscular force necessary for arm-lift is the contraction of the elevators of the humerus. And obviously as the humerus lifts, its distal skeletal attachments, fore-arm, hand, and fingers will be drawn after it. When pressure or weight is retained at the finger-tip, in spite of arm-lift, it can result only from a decided contraction of the muscles antagonistic to arm-lift. But simultaneous contraction of antagonistic groups always results in a hyper-tension, a stiffness, and consequently any arm-lift with sustained key-pressure in excess of that of the freely ascending arm, is, pianistically, an incoördinated movement. It is not arm-weight that is transferred, but a force resulting from muscular contraction opposed to arm-lift. The two are physiologically different elements and cannot be used synonymously in any adequate analysis.

The aim of arm-lift is either cessation of tone or preparation of the following arm-drop. Since we are dealing here with arm-legato, the first-mentioned aim may be discarded. In the second, the ascent of the arm becomes the negative, the descent becomes the positive aspect of the movement. Any hyper-tension in a negative movement becomes doubly disadvantageous since the movement itself is not directed toward meeting any external resistance.

Records made with the dynamograph show clearly what a small amount of weight is actually transferred from key to key. In fact a study of the numerical values showed this weight to be just sufficient to prevent premature key-ascent. If we now record the arm-lift which takes place at the end of a phrase and place the two curves side by side we note that they are markedly similar (Fig. 79), the dotted line representing arm-lift in one of a series of arm-legato movements, and the solid line representing arm-lift

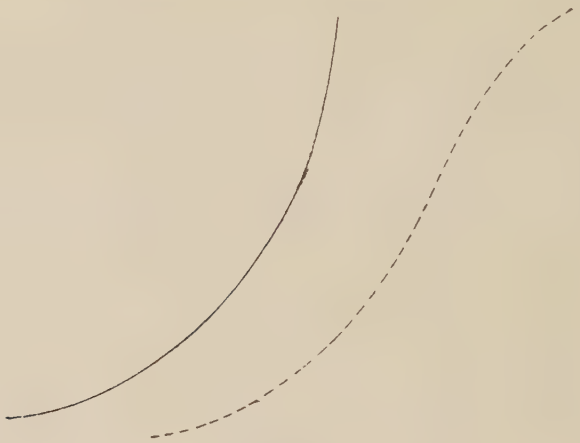


Fig. 79.

at the end of a phrase. A rise in the lines indicates weight-withdrawal. This agreement is further proof that in a proper arm-legato, weight is withdrawn between movements in the same manner as at the end of a phrase if the arm be relaxed.

Therefore, the two important facts to be remembered in connection with arm-legato are that the arm-weight is not transferred from key to key, over ninety per cent being withdrawn during each arm-ascent, and secondly, that the smaller finger and hand joints are not fully relaxed during tone-production.

CHAPTER XV

Tremolo

The essential feature of this movement is a turning of the fore-arm in the *radio-ulnar* articulation. If the upper arm hangs in any but a vertical position, contraction of the shoulder muscles is necessary to lift the arm against gravity from the side of the body and to hold it in this position while the fore-arm rotates. Contraction of the flexor muscles of the upper arm is needed to bend the elbow. Contraction of the dorsal rotators of the shoulder is required to keep the fore-arm in the horizontal position. Without this contraction the fore-arm would hang vertically from the elbow. Flexors and extensors of the wrist are contracted sufficiently to give the wrist the rigidity necessary to transmit the fore-arm rotation to the finger-tips without loss of motion at the wrist-joint. If this joint is relaxed it will ascend when the finger-tip reaches the key, because the resistance acts upward and produces movement in the nearest relaxed joint. This is shown in the staccato touches. If, for the present, we consider the octave-tremolo, contraction of the abductors of the thumb and fifth finger is needed to allow for the octave spread, and contraction of the thumb-abductors and fifth-finger flexors to overcome the key-resistance, which otherwise would push back the finger in the hand-knuckle. Once again then, the movement involves some contraction and adjustment throughout the whole arm and shoulder.

The movement itself is made by an alternating contraction of the pronators and supinators of the fore-arm. This contraction is not equal, because the mid-position of the fore-arm is not the horizontal position made necessary by the position of the keyboard. The unequal strength of the opposing muscle-groups, and the fact that the axis of rotation passes through the fourth finger and not through the third finger, are other causes of this inequality.

When the hand rests upon the keyboard the thumb and fifth finger support a part of the arm-weight. The abductors of the shoulder still remain contracted so that the elbow may retain its proper elevation, and this, of course, withdraws some of the arm-weight from the keys. The forward rotators of the shoulder and the biceps may relax because the keyboard relieves them of the

need for supporting the arm. The tremolo movement, therefore, when applied to the piano, may be made by resting alternately on thumb and fifth finger, or by poising the arm over the keyboard at a slightly higher level and turning in the radio-ulnar joint. In no case does tremolo originate in the elbow-joint. This, as a simple hinge joint, cannot permit motion around the longitudinal axis of the fore-arm.

Weight-transfer.

If the arm-weight (always only a part of the full arm-weight) rests alternately upon thumb and fifth finger, how is the transfer made from one to the other ? With the hand held vertically over

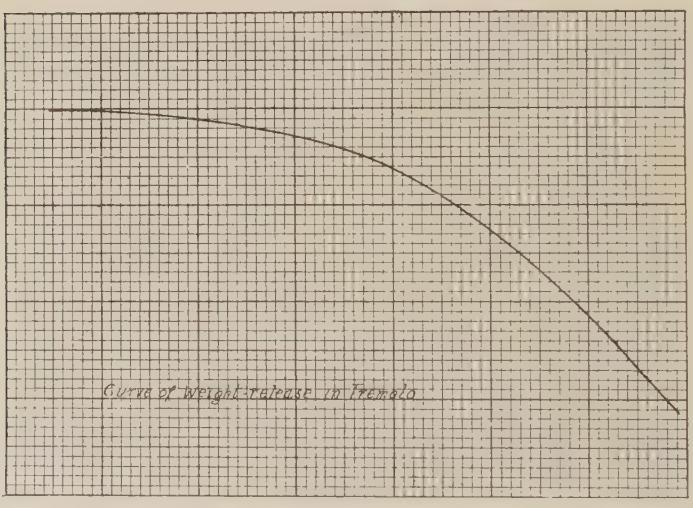


Fig. 80.

the thumb the centre of mass is in line with the point of support. As the right hand, for example, approaches the horizontal position the centre of mass shifts toward the right. The thumb-tip, therefore, loses in mechanical advantage and added muscular contraction is needed to keep the weight sustained. Or, conversely stated, as the hand approaches the horizontal there will be normally loss of weight on the thumb side, and an appreciable increase at the fifth finger as this depresses its key. The reversal of weight occurs when the hand turns from the fifth finger back to the thumb.

The curve for this weight release may be found by hinging an appropriately heavy rod to one end of a balance, the

level of which, by means of a recording point traces its movements on a kymograph. The rod may be placed in a vertical position and then permitted to fall freely to the horizontal position by means of the hinge, in which the friction must be reduced to a minimum. Here we have the mechanical equivalent of the weight-transfer procedure in tremolo. A typical curve obtained is shown in Fig. 80. The curve is typical of angular variations in force-action and can be deduced mathematically when we know the original force and the angles at which it acts.

It shows conclusively that as the rod begins to leave the vertical the loss of weight is small, but as it nears the horizontal it is much more rapid, reaching close to zero at the moment when the next finger depresses its key. That holds equally well for the so-called relaxed arm, the weight of which is supported by the finger. Consequently, if there is pressure retained uniformly on the first key, until the next is reached, it cannot be arm-weight, but must be a force resulting from muscular contraction. The mechanical and physiological conditions parallel those discussed under arm-legato, which also show the impossibility of weight-transfer.

A better proof of this absence of weight-transfer is found when we record the tremolo on a dynamograph. In this case it is quite impossible to keep the needle of the instrument at any fixed level, regardless of the speed at which the tremolo is played. At relatively slow speeds, the pressure drops to zero, at more rapid speeds the second impact catches the lever before it has had a chance to descend fully. The hand in such a case is turned less than in a slow tempo, hence the release of weight is naturally less than in a slow tremolo. The forces acting in fore-arm rotation as used in the tremolo touch are directed away from the key held, toward the key to be played. It is, accordingly, mechanically impossible to maintain weight unless additional muscular contraction, opposed to the tremolo itself, is introduced. And such an introduction would be incoördinated. The conditions prevailing are precisely those discussed in detail under weight-transfer. There it was shown that weight-transfer demanded for its magnitude and efficiency extremely slow sequence of movement and non-percussive attack, both of which, especially the slow tempo, are opposed to the arm tremolo. If a finger tremolo be substituted, we have the conditions of a trill, which likewise cannot be played with weight-transfer.

Tremolo Trills.

Among the important pedagogic problems resulting from the tremolo touch is the application of this touch-form to alternating

tones regardless of the size of pitch-interval involved : to the usual finger trill, for example. Various authors recommend its application without qualification, others strongly advise against it. A study of the mechanics of this motion will show to what extent its application from a physiological and mechanical standpoint is advisable.

In all fore-arm tremolo touches we are dealing with a rotary motion around an axis running approximately parallel to the long axis of the fore-arm. This rotation is shown clearly in the turning of a doorknob or the turning of a screw-driver. If during such a motion the thumb and the fifth finger are fully extended and abducted (as in an octave stretch), both thumb-tip and finger-tip will describe arcs of a circle. As the distance of the playing units to the axis of rotation becomes less, these arcs become less in extent, though they are subtended by equal central angles. This is illustrated in Fig. 81. And if, on the other hand, we keep the length

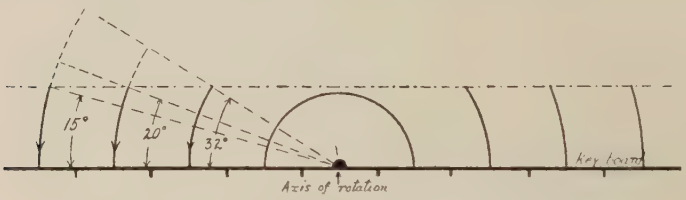


Fig. 81.

of arc (the distance through which the finger-tips move) the same, by increasing the central angle, we alter the direction and degree of curvature of the stroke, until in extreme instances, the finger would be travelling parallel to the keyboard through a part of its stroke, as shown by the smallest radius in the figure. All this is at a mechanical disadvantage for tone-production, and we may formulate the principle that the nearer together the two playing units are, the less useful is the tremolo motion. Octaves, sixths, and fifths lend themselves to tremolo in the order named, because the diameter between the two playing points is sufficiently great to produce effective arcs. Thirds are less good for fore-arm tremolo, but still possible. Seconds, the basis for all trills, can be played tremolo only at a decided mechanical disadvantage, which usually affects the tonal result also.

In any case of tremolo the hand must be so shifted (abducted at the wrist) that the axis of rotation falls midway between the playing parts. With the hand normally in line with the fore-arm

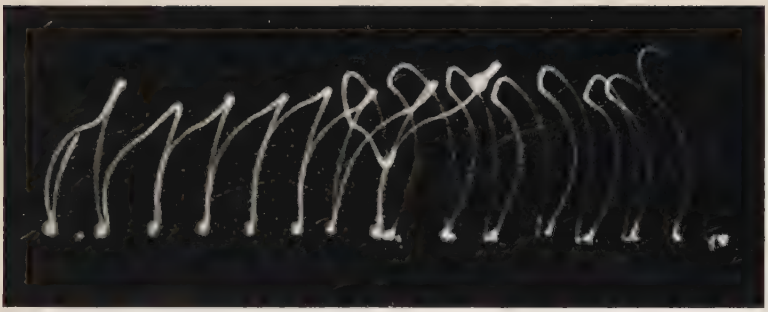


Fig. 82. Photographs of the movements of thumb-tip and fifth-finger tip in tremolo octaves, diatonic movement.

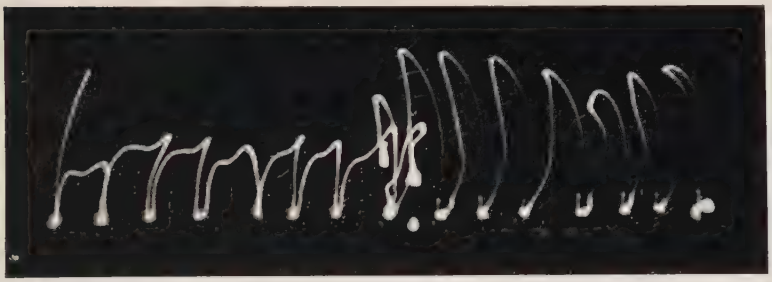


Fig. 83. Similar to Fig. 82, with addition of thumb-movement to fore-arm rotation.

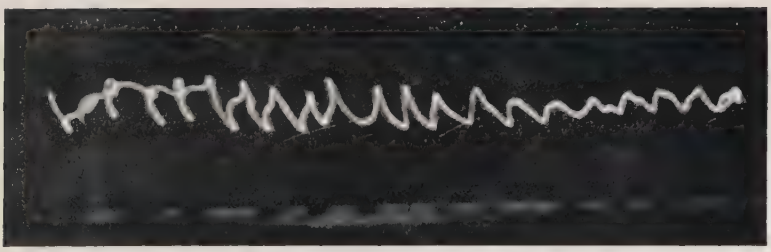


Fig. 86. Effect of intensity upon amplitude of tremolo-rotation. (Read from right to left.)

[*To face p.* 186

(the anatomical median position) this axis runs through the fourth finger, not, as is generally stated and believed, through the third finger. In order to make the third finger the centre for fore-arm rotation, the hand must be slightly abducted toward the fifth finger side. A tremolo performed with unequal distances from the axis would normally produce unequal forces and hence unequal tonal results. On the other hand, the physiological inequality of the pronating and supinating muscles, as well as the greater ease of supinating over a horizontal keyboard, must likewise be considered. If pivoting on the thumb be carried through ninety degrees, until the hand stands vertically over the thumb, the last part of the movement is normally accompanied by elevation of the upper arm, a part that is not at all used in pivoting on the fifth finger. Not all simple octave tremolos are played solely with fore-arm rotation, however. Very often some finger-action is added, particularly when it is desired to inflect the dynamics of the passage. A diatonic octave-tremolo performed primarily with fore-arm rotation is illustrated in Fig. 82. The curves of movement for the thumb and for the fifth finger, right hand, are shown as they would appear from the position of the player, if the eye were on a level with the keyboard. The pointed top is the curve for the thumb, the rounded top that for the fifth finger. This difference is the result of a small amount of thumb movement during the playing. (This flexion is more marked in Fig. 83.) Both the thumb and the fifth finger describe fairly concentric arcs around the single axis of rotation. Since the axis lies between the moving points, these arcs will curve in opposite directions. The nature of the curves is the same for both thumb and finger when finger-movement itself is excluded.

If finger-action be added to the fore-arm rotation in a tremolo, a curve such as that of Fig. 83 is produced. There is little difference in the part corresponding to the fifth finger, since this would make the stroke awkward, but a marked difference for the thumb. The stroke is considerably less in amplitude and is complicated by a bending-in of the thumb-tip (flexion) shown by the horizontal shift at the top of each thumb-stroke.

All the records of an octave tremolo with shifting hand, made under normal playing conditions, of which that in Fig. 82 is typical, showed some admixture of finger-action with the fore-arm rotation. That is to say, in playing tremolo octaves with changing pitch, the pianist normally does not restrict the movement entirely to the fore-arm rotation, but adds a little of finger-stroke. So that even in a movement, which, better than any other—with the exception of a finger-stroke or hand-staccato—could be restricted

to rotation about a single joint, we find movement at several joints contributing.

Various devices are resorted to by the player, when, in spite of obvious mechanical disadvantages, a trill on adjacent keys is played with an arm-tremolo movement. Thus it is not necessary that the fingers be adjacent. The hand may be cupped so that the tips of the second and fourth or even second and fifth fingers are brought close enough together to cover adjacent piano-keys. The lever arm is then the distance between the hand-knuckles of these fingers, and this being considerably greater than the distance between adjacent fingers, the arm-tremolo touch becomes somewhat easier. It is, however, a makeshift at best. The mechanics of the problem place a trill among the finger-strokes, and not among the tremolo touches.

Finger-tremolo.

This leaves the opposite phase to be considered, that of performing an octave tremolo without fore-arm rotation, by means of finger-stroke.

In our study of hand-position, the difficulty of finger-flexion with finger abduction was pointed out. It is much more difficult to use a descending finger-stroke freely when the fingers are "sprawled", as in extended chord work, than when the fingers are in the familiar "five-finger position". The reason for this is in the skeletal and muscular structures of the hand, which make it impossible to bend the fingers in the hand-knuckles and at the same time separate (spread) the fingers widely. With abduction we must have extension. Accordingly, to use a finger-stroke (flexion) with the hand extended into the octave position, is, normally, to use the stroke at a physiological disadvantage. The muscles making the hyper-thenar eminence, however, make such a movement possible, chiefly for the fifth finger, and lessen the physiological disadvantage.

The chief physiological advantage of the finger-tremolo over the arm-tremolo, however, is not in the muscles of the fifth finger, but in the reduction of the factors of inertia and momentum to a minimum. We have seen that any rapid movement requiring a quick change of direction is most economically made with a light body. The fingers are much lighter than the arm; and since the tremolo touch demands a complete reversal of direction, the fingers can execute this much more easily than the heavier arm. Although arm-tremolo is a rotary motion, this motion stops at each key-contact and reverses. And at these points the momentum of the

moving mass very noticeably affects the amount of muscular contraction required to reverse the direction. Assuming the speed of finger-descent to be the same in both cases, it will take considerably more force to reverse the arm than to reverse the finger. (See Mechanical Principles.) This two-fold requirement recurs at each key-contact, and the waste in energy for a prolonged tremolo can readily be inferred.

When the intensity demands exceed the muscular strength of the fingers, arm-rotation may advantageously be added or substituted. But for all soft and moderately loud degrees, the finger-tremolo is much better. It permits better control of tone and less expenditure of energy, hence it is a better coördinated movement. This is again a concrete illustration of the need for finger drill in order to strengthen the finger flexors lying in the hand. As

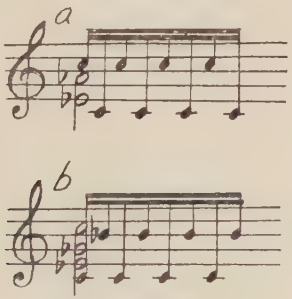



Fig. 84.

a matter of fact, not a few concert pianists, Josef Hofmann among others, always use the finger-tremolo under the conditions here outlined. The stiffness which often accompanies a pupil's attempt at finger-tremolo results, invariably, from an insufficient strength in the finger muscles. The movement is not at all awkward once this strength has been secured. Moreover, a figure such as that given in Fig. 84*a*, cannot readily be played except with finger tremolo. 84*b* can be played only with finger-tremolo.

Fingering.

Turning the hand laterally at the wrist permits a wide range in the fingering of tremolo figures. But not all fingering is equally effective. Taking an interval of a fifth as an example, the fingers used may be 1, 2 ; 1, 3 ; 1, 4 ; 1, 5 ; 2, 4 ; 2, 5 ; 3, 5. In each case the hand will be so turned at the wrist that the axis of rotation will be brought to an approximate mid-point between

the finger-tips used. This equality of division is necessary on account of the mechanical principle shown in Fig. 81. When 1 and 2 are used, the mass of the hand is almost entirely on the outside of the second finger. With each rotation of the fore-arm this mass rotates. The centre of mass of the hand thus lies considerably to one side of the axis of rotation. Its arc of rotation is, therefore, relatively great and the centrifugal force generated, relatively large. The constant change of direction of this mass, demanded by the tremolo touch, thus becomes mechanically awkward. The same difficulty exists, in an opposite direction, when 3 and 5 are used. It is present to a less extent when 1 and 3 are used. Accordingly, the rule to be followed in a tremolo fingering is to use that fingering that permits the centre of mass of the moving part to be as nearly in the axis of rotation as possible.

Here, too, we find the value of a finger tremolo. If, for example, a tremolo be demanded from 1 and 2, and the use of other fingers be excluded, the tremolo should be made with finger-action not fore-arm rotation. When the finger-stroke is used, the hand remains relatively quiet, no arm-momentum is created, and the difficulty of the alignment of the centre of mass is thus eliminated.

Chord-Tremolo.

A type of tremolo frequently found in piano literature is the chord tremolo : a rapid alternation of the tones of a chord, grouped in various ways. Some of these forms in the case of a six-five chord and a sixth-chord on C are shown in Fig. 85.

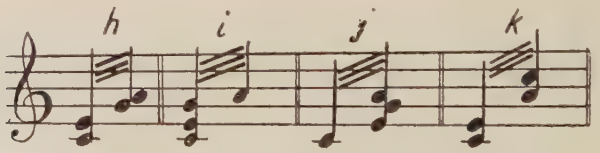



Fig. 85.

To the factors already mentioned is here added that of inequality between the lower and upper group of tones (*i*, *j*). In *i* the force necessary to produce equality of tone in top and bottom groups is three times as great for the lower as for the upper group. This relationship is reversed in *j*. Moreover, the three finger-tips must strike the keys simultaneously, hence they must be carried in one line. The tremolo, therefore, lies between the tones *e* and *g* in *h* ; *g* and *a* in *i* ; *c* and *e* in *j*, and *e* and *a* in *k*. The first group may advantageously be played with fore-arm tremolo since the mass

of the moving part is distributed on both sides of the axis of rotation. *i* and *j*, however, cannot readily be so played.

In the first place, in both cases the centre of mass is to one side of the axis, and in the second place, the three fingers striking simultaneously are moving at different speeds, as a reference to Fig. 81 will show, if a fore-arm tremolo motion be used. The rule in such cases is to use a finger-stroke without fore-arm rotation. Even though the tones can all be played with a fore-arm tremolo, the differences in tonal intensity and agogic evenness will spoil a finished tremolo effect. The extreme tone will always be accented on account of the maximal speed of the fifth finger, which is furthest removed from the axis of rotation. So long as a pure fore-arm tremolo is used these speeds—hence force-variations—follow as a mechanical necessity.

Such chord tremolos, therefore, are always difficult for pupils who depend entirely on fore-arm rotation for tremolo effects. The degree to which the arm-tremolo should be used in chord figures, depends, first upon the equality of the number of tones distributed on the two sides of the axis of rotation, and secondly upon the distance between the two tones nearest the axis. *k*, Fig. 85, is better adapted to a rotary tremolo than *h*, although in both cases the tones are equally distributed with regard to the axis of rotation : two on each side. The difference lies in the distance between *e* and *a* in *k* and *e* and *g* in *h*. *i* and *j* in Fig. 85 are more difficult than *h* or *k* because in the former group the tones are unequally distributed. The more unequally the tones are grouped and the closer the groups stand, the more should finger-action replace fore-arm rotation. It is on this account that immature pupils find such tremolo figures exceedingly difficult, as those in the Waldstein Sonata of Beethoven, or in many of the orchestral transcriptions. The passages are not effectively playable with the simpler fore-arm rotation, and the fingered tremolo is not yet in the workable vocabulary of the student.

Speed.

The effect of speed on tremolo is likewise a transfer from arm-weight to arm-stroke. The acceleration equals the force divided by the mass. Assuming the force (intensity) to be constant any increase in mass will reduce the velocity. If the force be 10 and the mass 2, the velocity will be $\frac{10}{2} = 5$. An increase of the mass to 4 will halve the velocity. Accordingly, we avoid this difficulty by substituting fore-arm stroke for fore-arm weight. That is to say, we reduce the mass and thus increase the velocity. This phase is discussed in detail under weight-transfer.

Rapid tremolos, therefore, are from a muscular standpoint non-legato touches ; the weight is not shifted from thumb to finger, or finger to finger. Instead, the arm-weight is fully carried by the shoulder-muscles and the key-depression is produced by the descending fingers, the descent of which results from the contraction of the supinators and pronators of the fore-arm, or from finger-stroke, and not from the action of gravity. Here, again, is an instance of a non-relaxed touch-form ; the arm instead of hanging in the keys, is poised above them.

Speed, moreover, diminishes the distance through which the playing parts move. The greater the speed, the less actual movement in the finger-paths, and the more muscular contraction to make up for the loss in distance, since, so long as intensity is the same, the finger must reach the point of escapement with the same velocity.

Intensity.

With speed constant, the effect of increasing intensity upon the tremolo movement is to add muscular contraction to arm-weight. Force being the product of mass and acceleration, it may be increased either by increasing the mass or by increasing the acceleration. If, by adding arm-weight we increase the mass, we also increase the inertia. A heavy body moving slowly may produce the same force as a light body moving rapidly. The inertias of the two will be different, however, because the masses are different. The direction of the light body may be changed much more readily, and since in tremolo this change of direction occurs at each stroke, top and bottom, it is mechanically preferable to increase the velocity instead of the mass. This is done by forceful contraction of the supinating and pronating muscles while the upper arm is poised by the shoulder muscles. An active down-stroke replaces the action of gravity upon the fore-arm. Only when the rate of succession of the strokes is extremely slow is the use of arm-weight advisable.

Dynamics.

If spread of muscular action is a necessary mechanical result of increase in tonal intensity, we should expect to find this spread in the tremolo touch when this is accompanied by a crescendo. Fig. 86 shows a diatonic octave tremolo, ascending, from *p* to *f*. The observer is looking across the keyboard at the player. Consequently, from right to left on the figure is ascent on the keyboard. The point of light was attached near the elbow. The minor

fluctuations in the curve are probably due to some play in the recording apparatus. But the increase in amplitude as the tones become louder is clearly evident as we pass from right to left.

Asymmetry.

The range through which the fore-arm may be rotated is approximately a straight-angle, 180°. But, as I have already pointed out, this range does not have the horizontal hand-position as its middle. When, consequently, we rotate the hand equal distances from the keyboard the muscular contraction is not equal on both sides. It is more difficult to pivot on the thumb than on the fifth finger, for the range on the fifth finger side is much larger. The turning into the position in which the thumb is over the fifth finger is a free, easy movement; that requiring the fifth finger over the thumb is decidedly less so, because here we begin the motion at the limit of fore-arm pronation and must resort to humerus abduction. A fore-arm tremolo, therefore, is not a balanced, reciprocating or symmetrical alternation, but an asymmetrical

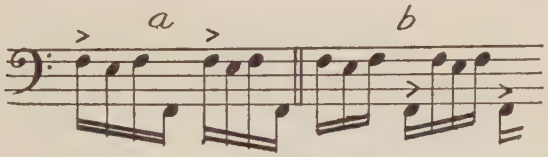



FIG. 87.

movement, in which the movement of the thumb differs somewhat from that of the little finger. Such a difference has already been shown in Fig. 83 in curves made by the thumb-tip and fifth finger-tip in a rapid diatonic tremolo. The curve beginning on the left is that for the thumb; that beginning an octave higher (middle of the record) is that for the fifth finger. The observer faces the keyboard, the curves are as they would appear to the player if his eye were on a level with the keyboard. The details of recording are described in Lateral Arm-Movement.

But the asymmetry of tremolo is the result also of differences in the normal strength of the two muscle-groups. The muscles of supination are stronger than those of pronation. In forcing a screw-driver we do so with the stronger group: the supinators. As a result of this difference the accentuation of the fifth finger is easier in an octave tremolo than that of the thumb. The tendency of pupils to play passages such as that in Fig. 87, *a*, with the accent as at *b*, is, in part at least, the direct result of this muscular difference.

o

In teaching fore-arm rotation movements of pronation and supination are usually taught simultaneously. From a physiological stand-point, supination is much more natural, hence may advantageously be taught first. It plays a much more important rôle in piano literature than the pronation. In point of biological fundamentality fore-arm motion is an early coördination. Its use in even elementary piano work need not, therefore, be deferred. Small children use it freely, since it is a natural physiological movement. At the same time, in some modified form it is in almost constant use in any advanced piano technique. Pronating beyond the horizontal hand-position (pivoting on the thumb and bringing the fifth finger over it) is a less natural movement at that range and demands much more training for its proper acquisition. As a result we frequently find a typical irregularity in the tremolo of pupils insufficiently prepared and this irregularity may often be traced to the added difficulty of excess pronation. The two touches, supination and pronation, may well be taught separately to advantage, before combining them, since physiologically they are not reciprocal movements.

Another phase of the tremolo movement that is often overlooked is that, as soon as the movement is carried beyond the point where the fifth finger comes into contact with the key, the movement changes from a fore-arm to an upper arm rotation. This is inevitable, because the hand is lifted as it rests upon the fifth finger and a lift of the fore-arm, with bent elbow can occur only with rotation of the upper arm in the shoulder-joint. Therefore, if the pedagogic problem be to drill fore-arm rotation, the movement should be carried only to the point where the fifth finger depresses the key, and not to the vertical position over the fifth finger. The latter position, unless the hand sinks upon the key or is awkwardly flexed at the wrist, can be reached only with some upper arm (humerus) rotation.

Finally, the best range of the keyboard for practising the tremolo at the beginning, is the point at which the elbow is approximately flexed to a right angle with moderate humerus abduction. This would be about the first octave above the treble clef for the right hand when the player is seated normally at the keyboard. Further extension than that begins to result in adding some upper arm rotation, while playing nearer the centre of the keyboard demands an abduction at the wrist that interferes with the proper projection of the axis of rotation.

Relative Intensity.

The value of fore-arm rotation, which is nothing more than an elaboration of the tremolo movement, is determined also by the

relative intensities of the tones comprising the passage in question. In a spread chord-figure, for example as at *a* Fig. 88, it is perfectly easy to accent the end tones by using the fore-arm rotation. But let the metrical accent fall on an intermediate tone as at *b*, and the tremolo or fore-arm rotation not only becomes useless, but also interferes seriously with the adequate performance of the movement. In such cases finger-strength is the only safe means of securing the dynamic contrast. It is this relationship that is at the bottom of such typical difficulties as those in the first Czerny Etude in the School of Velocity, where the right hand has the D accented in the descending figure F-E-D-A, and the closing measures of No. 9, where the accent is demanded of the fourth finger with the fingers in an abducted position: the most difficult position for such an accent. Parts of Mendelssohn's Spinning Song are further examples.

Fig. 88.

Such figures point out clearly the need for developing finger-strength as against the arm-weight pedagogy, and for useing finger-tremolo instead of fore-arm tremolo.

Movement-Phase.

In the arm-tremolo touch the positive and negative phases are not readily kept apart. This is because the movement is one of fore-arm rotation, and the rotation in either direction is movement toward tone-production. Both sides, therefore, are positive movements. Moreover, since the depression on one side is necessarily accompanied by a corresponding ascent on the other side, the thumb passes through its positive phase as the fifth finger passes through its negative phase, and vice versa. But, so far as the fore-arm movement itself is concerned, it has no negative phase. Consequently, this characteristic of many piano touches is absent in the tremolo touch.

CHAPTER XVI

Staccato

The two essential characteristics of all staccato touches are the shortness of the tone and its tonal separation from the preceding and succeeding tones. A tone merely of short duration, but connected to some other tone is not a staccato tone, regardless of its own agogic value. Nor is a tone staccato when it is merely separated from other tones. Both brevity and tonal isolation are necessary for a true staccato effect. Just where this brevity and tonal isolation begin or end is a point often difficult to determine. Variations in them shade by imperceptible degrees into non-staccato, and light portamento. All such terms, we must remember, are but convenient designations along a continuous scale, and the terms become definite only when the salient features are well marked. Consequently, in the following analysis of the staccato touches, both brevity and isolation will be assumed to be clearly present.

Staccato touches differ from legato not in their effect on the beginning of tone, but on the ending of tone. Key-release, not key-depression, becomes the physical determinant. The piano-key, contrary to popular belief, is not an elastic body in the sense that its ascent results from an elasticity with compression by the preceding descent. It rises because of impact with its reversal of force-action, and because the inner arm of the key-lever is heavier than the outer and is pulled down by gravity when resistance on the outer, lighter arm is released. The direction in which the arm is held during key-release has no direct effect, since the movement of the piano-key is fixed both as to range and direction, and up to a certain point also as to speed. By lifting the hand very rapidly from the key we do not hasten the key's ascent. This is fixed by the action of gravity, and affected only to a very small extent indeed by the force of the rebounding hammer, the check of which is so constructed that this force acts at a very poor angle with regard to the rebounding hammer. The finger can delay key-ascent to any desired degree, but it cannot accelerate it beyond the point established by the construction of the action.

This independence of key-ascent from finger-ascent is illustrated in Fig. 89 in which the curves represent the ascent of the piano-key.

a shows the ascent for a light staccato, *b* for a *forte* staccato, equivalent to a *martellato*. The time-line is in fiftieths of a second. Regardless of the speed of key-depression, its ascent remains both slower and irregular, in these cases requiring between 2 and 3 fiftieths of a second for its completion. Fig. 204, in the chapter on Tone Qualities, also shows this impossibility of accelerating key-ascent. The upper line in this figure records the ascent of the finger itself, the lower line that of the key. Hence the finger-tip leaves the key-surface a moment after key-ascent begins, while the key continues its ascent at a much slower rate. Since tone-beginning takes place practically at the moment of hammer-escapement, represented in these curves at a point near the bottom of the curve, the shortest tone possible on the piano with full key-depression, measured solely by key-movement, lasts approximately two-fiftieths of a second. Under all practical conditions it is considerably longer.

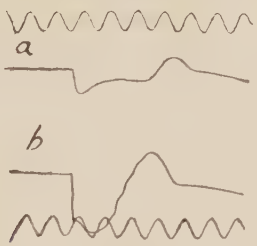


Fig. 89.

The duration of the contact of finger-tip and key, in these touches, is not equal to that of the tone. The tone produced is longer than the finger-key contact and the extreme *staccatissimo* effects are an auditory illusion resulting from the brevity of the kinesthetic and visual sensations. The tone is not as short as we imagine it is. (See in this connection the paragraph on Imagery in the chapter on Tone Qualities.)

This digression into the physical field was necessary in order to account for the adoption of certain movements for staccato effects. The purpose of all staccato effects is shortness of tone, which in turn demands key-ascent. The appropriate touch is one permitting the key to ascend as soon as possible. Since all tone-production begins with some form of down-stroke, the change from down to up-stroke becomes the crucial point in staccato touches. This change involves a marked change in direction, which, in turn, consumes time. Such an abrupt change in direction, as we shall

learn later, is difficult from a physiological, and awkward from a mechanical point of view.

In staccato touches the weight of the arm is carried by the shoulder muscles. There can be no weight resting upon the keys in any staccato form. A part of the arm is then permitted to fall upon, or is forced down upon the key, whereupon it is immediately withdrawn. According to the part thus used, the type of touch is called hand, arm, or finger staccato.

Hand-Staccato.

In this touch the hand is the playing-unit. Fore-arm and upper arm are held stationary over the key-level. The dorsal flexors of the wrist are held contracted to keep the hand from falling upon the keys. When these muscles are relaxed, the hand will descend upon the key either through the action of gravity, or through

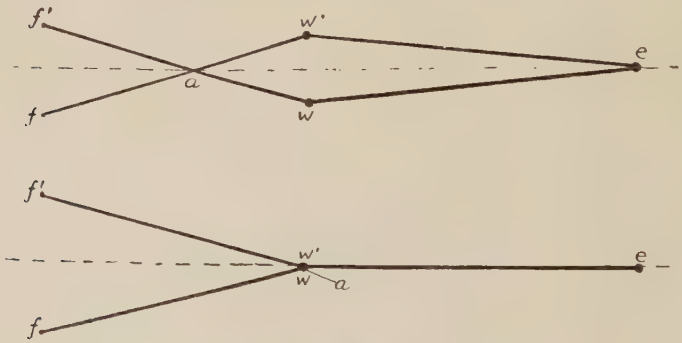


Fig. 90.

appropriate contraction of the volar flexors. The problem of individual differences has a direct effect here. The production of tone demands a certain velocity at key-impact. The hand of an adult, weighing normally between half a pound and a pound, may gain the desired velocity of its own weight. The hand of a child, weighing considerably less, will gain less velocity. If the latter be insufficient it can be increased only by adding appropriate muscular contraction to the falling hand. As the hand reaches the key, the extensors of the wrist are rapidly contracted, bringing the hand back into its original position. At the moment of key-impact the force adjustment at the finger-tip carries over into the wrist and produces the wrist-jerk, typical of all staccato touches. This jerk must not be confused with the wrist-ascent resulting from

a shift of the fulcrum forward from the wrist, as shown in Fig. 90. Here the wrist rises and falls as one end of a lever the fulcrum of which has been shifted from the wrist as in the lower figure, to a position between the wrist and the fingers, as at *a* in the upper figure. The lower illustration shows a true hand-staccato. Physiologically and mechanically they are different movements.

The wrist-jerk is a necessary mechanical resultant of the finger-key impact. The muscles responsible for key-depression are acting downward. Their function is to change the angle of the bones at the wrist, for in a true hand-staccato the wrist is the only joint in which motion occurs. When the descent of the finger-tip is stopped by key-resistance, the continued contraction of the hand-flexors will increase the angle of flexion by raising the wrist. The mechanical principle operating here is that analysed under shift of fulcrum in the preceding paragraph. (See also Action and Reaction.) The mechanical arm illustrates it quite nicely so far as the actual

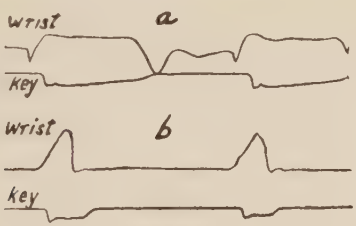


Fig. 91.

direction of motion is concerned, whereas the following experiment will demonstrate the distribution of the forces.

Since hand-staccato demands a relatively stationary wrist, this may be placed upon a spring balance, appropriately arranged in front of the keyboard. The balance will then register the weight of a part of the arm. Of course, in an actual staccato this weight is carried by the arm muscles. If, now, the hand be thrown against the keys in a typical staccato touch, the balance will show a reduction in weight at the wrist, at the moment of finger-key impact. This reduction varies directly with the amount of force at the finger-tip, whether the strokes be intermittent, or whether a sustained pressure (necessarily non-staccato) be employed. Typical curves are shown in Fig. 91. The curve for the key was made by a pneumatic recorder placed beneath the piano-key, so that addition in pressure was reflected by a greater displacement in the recording pen. Depression in this line indicates pressure,

the deeper the depression, the greater the pressure. In the curve for the wrist, which was made by attaching an appropriate stylus to the spring balance carrying the wrist, greater upward deflection means greater loss of weight. An ascent in this line, therefore, shows a release of weight—hence an upward acting force—a descent in the line, an increase in weight. The curves *a* show the distributions of the forces for a sustained (non-staccato) touch, those at *b* for a staccato touch. The interaction is clearly seen: a depression of one line is accompanied by an ascent in the other line.

Moreover, in the slow touch-form of sostenuto, shown at *a*, time is lost in bringing the weight at the wrist down sufficiently to enable the finger to depress the key. This phase of movement has been discussed in detail under Coördination. With the arm resting freely at the wrist, or in other words with the wrist in full relaxation, the finger would have no fixed fulcrum from which to work—for the wrist fixation determines the hand-knuckle position. So that

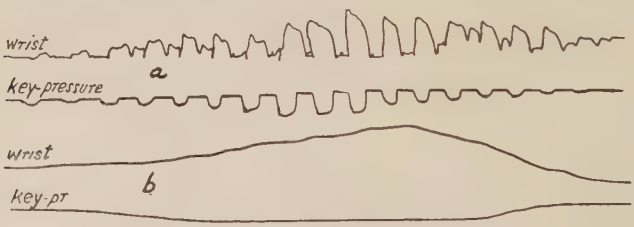


Fig. 92.

the actual depression of the piano-key is preceded by a slight fixation of the wrist, which in turn releases a small part of the weight. For this reason we find the wrist line in *a* of Fig. 91 beginning its rise slightly in advance of key-depression. In the rapid staccato touch this difference is too small to show on the scale of projection here used.

The fact that the actual amount of weight-release at the wrist parallels the increase at the finger-tip may be demonstrated by recording the movements in a series of staccato touches making a crescendo and diminuendo. If the observations just made are true, the deflections in both lines should increase with the crescendo and decrease with the diminuendo. Fig. 92 *a* shows this to be so. *b* in the same figure illustrates the force-distribution at finger-tip and wrist when the crescendo and diminuendo are made with unbroken pressure. Pianistically, of course, such a touch is absolutely useless. It serves, however, to show beyond any doubt the interaction of the forces we are considering.

In order to overcome the key-resistance promptly and effectively the finger-joints must be fixed sufficiently. The tendons producing flexion of the nail and middle finger-joints pass under the wrist. Excessive flexion of the fingers, accordingly, would increase somewhat the difficulty of keeping the wrist-joint relaxed since the tension of these tendons would inhibit complete freedom of movement. This would aid in hand-descent, but interfere in hand-ascent. Fingers, curved only in nail and first interphalangeal joints, therefore, make a hand-staccato touch more difficult. Contraction of the hand-muscles, producing flexion at the hand-knuckles, relieves this tension on the wrist because, of the three sets of muscles situated in the hand, all of which contribute to the flexion of the first finger-joint (next to the hand-knuckle), two sets take their origin from the sides of the bones in the hand. As a result the contraction of these muscles is without effect on the wrist. The remaining set, the lumbricales, although they have their origin in the flexor tendons that pass beneath the wrist, exert a pull in

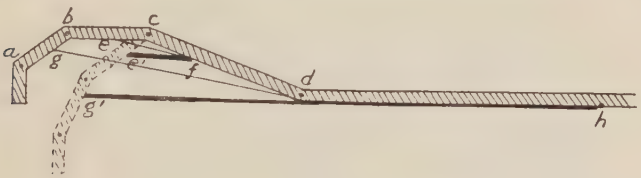


Fig. 93.

an opposite direction to that of the finger-flexors themselves. These effects are shown in Fig. 93, in which *a*, *b*, are finger-joints ; *c*, hand-knuckles ; *d*, wrist ; *e f*, tendon and muscle of one of the palmar muscles ; *g–h*, tendon of the flexor of finger-joints. When the finger-joint *b* is flexed, the tendon *g–h* becomes shorter and exerts a mild pull on *d*, striving to get a straight line between *g* and *h*. This resistance must be overcome by lifting the hand backward at the wrist during such a contraction. If, instead of this contraction, the palmar interossei contract *e-f* will take the position shown by e^1-*f*, a change which in no way affects the wrist, while still bringing the finger-tip into playing position.

For the same reason any finger-action during the hand-staccato stroke makes the latter more difficult to execute, because movement in the finger-joints is normally accompanied by a compensatory fixing of the wrist in order to meet the resistance to be overcome. And this fixing of the wrist interferes with the freedom of wrist-movement in hand-staccato. The fixing likewise accompanies

abduction of the fingers, which, as we have seen, is closely linked with extension of the wrist. To flex the wrist while the fingers are widely spread is an unnatural, and, at first, tiring movement and accounts for the "tired wrist" of pupils beginning staccato octaves.

The natural procedure to follow in the teaching of hand-staccato is first to arch the hand by contracting the palm muscles, and then to keep the fingers close together. A very useful position is that shown in Fig. 94, playing single keys with the third finger. The thumb being pressed against this finger makes finger-movement impossible. The drawing under of the fourth and fifth fingers is the opposite extreme of the spread fingers. Consequently, the hand is in the most favourable position for hand-staccato. From such a position the transition should be made to playing staccato thirds with second and fourth fingers; and then to wider intervals, reserving octaves until all intervening intervals have been mastered.

The distribution of muscular activity is further complicated by the actual position of, or the amount of curvature in the fingers. With the nail-joint striking the key in an approximately vertical position contraction of the muscles controlling action at this joint is materially reduced since the position directs the force of key-resistance against the bone-ends. Flat fingers demand contraction of the flexor profundis to prevent breaking-in of the nail-joints, and this contraction influences wrist movement since the tendon of this muscle passes under the wrist. Curved fingers are therefore preferable to flat fingers in teaching hand-staccato. The thumb and fifth fingers have their own flexors (flexor brevis pollicis and flexor brevis minimi digiti) and hence these fingers may be flexed without affecting the wrist-joint as affected by the other fingers. The origins of these muscles lie in the hand itself, that of the former in the trapezium and the front of the annular ligament; that of the latter in the carpal bones. On this account it is advisable to begin the staccato work of the first and fifth fingers with intervals as small even as a third, leading by steps into the octave. The basic fact to remember, in all hand staccato touches, is that the wider the spread of the fingers, the greater the fixation of the wrist.

The presence or absence of muscular contraction in the descending part of the hand-staccato may be determined by the pneumatic tambour. This is held against the flexor carpi radialis, the muscle controlling volar wrist flexion. The muscle is prominently situated in the under part of the fore-arm. If the hand is thrown against the key, this muscle will contract at the beginning of hand-descent. A typical record is given in Fig. 98, where the upper line records

Fig. 94. Hand-position useful in eliminating all finger-movement in hand-staccato.

[*To face p.* 202

the contraction of the muscle, the lower line the key-depression. The muscular contraction has taken place entirely before the key is reached; the two arrows showing respectively the beginning of contraction and beginning of key-depression. Difference in time is five-fiftieths of a second.

Arm-Staccato.

In this touch-form the wrist is relatively rigid and the fore-arm, or, sometimes, the whole arm is thrown against the keys. The manner in which this is done depends largely upon the part of the keyboard used, because the touch remains a vertical descent and ascent, and the effect of the region of the keyboard upon vertical arm-descent has been analysed on p. 25. (See also Fig. 95.)

Since the part moving has a greater mass than the hand alone, and since the duration of tone is supposed to be just as short, it follows that a greater muscular contraction will be needed to control the change of direction at the moment of impact. It follows also, other things equal, that the force acting upon the key will be greater, if the velocity of the descending hand equals that of the descending arm.

If the entire arm is used its descent results from a relaxation of the shoulder muscles, thus letting gravity act on the arm, or from contraction of the arm adductors and depressors. Motion takes place in the shoulder-joint; and motion in the elbow takes place in inverse ratio to the angle of humerus abduction. A marked degree of muscular fixation is necessary for this touch-form, particularly when elbow-flexion approaches a right angle and the humerus is held horizontal. In this case the point at which key-resistance acts is at a considerable distance from the axis of depression, which is at the elbow. The resistance of the keys, therefore, at this leverage introduces a considerable force which tends to rotate the humerus backward. To overcome this the forward rotators are contracted. Moreover, the leverage system at work in such a touch is at a mechanical disadvantage in producing force at the finger-tip, because the leverage gains in speed, hence loses in force. I can find neither physiological nor mechanical advantage in playing staccato from the entire arm.

The usual fore-arm staccato results also from a rotation of the humerus, plus elbow flexion and extension; but since the elbow is lower than in the case just cited, the leverage has a mechanical advantage. (See p. 128.) When the humerus is vertical the interaction of forces is, therefore, direct and opposite. The necessary adjustment at the moment of reversal of direction is more accurately

made because no forces are acting to produce motion outside of the plane of movement. As the upper arm is drawn nearer the side of the body the movement of rotation in the shoulder gradually gives way to an extension and flexion of the elbow. The favourable plane of action remains. As a matter of fact the so-called fore-arm staccato that results from humerus rotation is not a fore-arm movement at all. It is a whole-arm movement, with the participation of the humerus obscured by the fact that this bone is rotating on its own longitudinal axis, hence does not itself change its spatial relationship to the body.

Change of Position.

In playing, let us say, diatonic staccato octaves with the right hand from middle C ascending through two octaves, we begin with a movement almost entirely elbow flexion and extension (see Fig. 95), and we end with a movement that is almost entirely

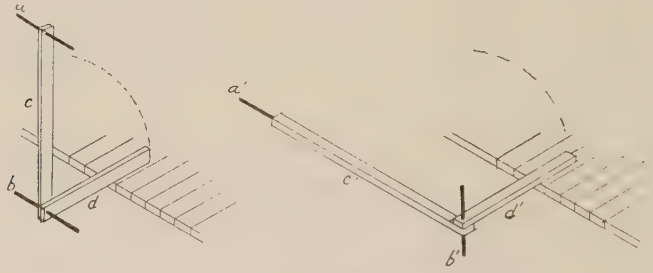


Fig. 95.

humerus rotation. To speak of an arm-staccato, therefore, regardless of its exact location on the keyboard, is to ignore the underlying physiological basis. If the keys played are near the centre of the keyboard the movement is made by the fore-arm, acting at the elbow; if played near the extremes of the keyboard the movement is made by rotation in the shoulder. Naturally, entirely different muscular coördinations are needed. The muscles bending and extending the elbow are situated in the upper arm: biceps, brachialis, brachioradialis, and pronator-teres for flexion, triceps for extension, whereas those rotating the shoulder are located in the chest, neck, and upper back: subscapularis, infraspinatus, and teres minor. The transition from one to the other extreme as the hand ascends along the keyboard is very gradual and is another striking illustration of the fallacy of muscular isolation.

For the sake of more clearly illustrating this shift of coördination the two extremes are shown in Fig. 95, drawn in isometric projection

so as to take care of the several planes of movement. When near the centre of the keyboard, the vertical movement of the hand (shown by the dotted line) results from d rotating on axis b. When the hand has reached the high treble region the positions of the upper arm and lower arm are approximately as shown in c^1 and d^1. In this position vertical movement of d^1 can take place only by rotation around axis a^1, since axis b^1 is in line with the plane of motion.

Dynamic Variations.

The effect of variations in tonal intensity upon the muscular coördinations used in staccato touches is similar to that in other touches: the greater the intensity the greater the spread of muscular activity, both as to movement and as to fixation. The increase in force demanded by an increase in tonal intensity may be gained either by increasing the velocity of the playing body or by increasing its mass. An increase in velocity means a more intense muscular contraction and a correspondingly greater fixation to take care of the reaction. Thus, in hand-staccato, it is possible to increase the intensity of the tones without resorting to arm-staccato, by a more powerful contraction of the wrist-flexors. But the position of the parts is such that the gain in force, resulting from a gain in speed, works at a mechanical disadvantage, because force, not speed, is the aim of the movement. Consequently, to play staccato octaves, let us say, *forte* or *fortissimo* by violent contraction of the wrist flexors, is to work at a decided physiological disadvantage. I know of at least two instances where failure to take the underlying mechanical principles into account resulted in a tearing of the flexor of the fifth finger, where it passes the wrist. This, by the way, is at least one example where a knowledge of the muscles, their function, and the mechanical principles involved would have been of decided practical value.

The second means of securing the desired dynamic degree is to increase the mass of the playing-unit. This method substitutes the arm-staccato for the hand-staccato in the louder tones. Since the hand no longer need turn at the wrist as an axis, its position may be changed so that the key-resistance acts against the skeletal structure of the hand. Finger, hand, and fore-arm are brought more nearly into the skeletal position (Fig. 186). The change from the position of hand-staccato is not abrupt. A succession of staccato octaves, for instance, with a crescendo of sufficient range will begin with a pure hand-staccato and end with an entire arm-staccato, with all grades of admixture between. Here, again, the muscular

coördination used at the beginning will differ radically from that used at the end. Muscles used to fix a joint are later used to move it ; others used to move a joint are later used to fix it.

Fig. 96.

Not only the spread of activity through the upper arm marks a staccato crescendo, but also the position of the arm itself. The latter varies in accordance with the principle of substituting the resistance of the bones for that of the muscles to any force of considerable intensity.

Agogic Variations.

The influence of speed on staccato may be learned from the study of any repeated movement. Assuming the position of the arm to be stationary in regard to the region of the keyboard used—as, for instance, its use in repeated octaves—we have for study a rapidly alternating movement of hand or arm descent and ascent. As the speed increases the time for changing descent into ascent becomes less. The contracting muscles will, therefore, act more strongly, and this type of contraction plays over into adjoining parts which act as points of relative fixation. This gives rise to the familiar spread of tension which accompanies an increase in the speed of repetition of a movement. A conspicuous illustration is furnished by the tapping test. The standard form of this test is given on a metal board tapped by a metal stylus held in the hand. Such a procedure destroys the most salient feature of the individual responses. By using an improved form of recording lever—a dynamograph of which the amplitude of the stylus fluctuations records variations in force—this difficulty is eliminated. Three sets of records are given in Fig. 96. They represent the curves obtained when a pupil is asked to tap " just as rapidly as possible, to see how many taps you can make in a given time ". The top set of curves shows the result for a very talented, trained pupil who used an extremely light touch, accompanied by a gentle steady raising and lowering of the wrist, thus combining the taps into muscular higher-units. These are shown by the wave-like crests. The middle set of curves were made by a pupil of normal technical ability. They show greater expenditure of force and a moderate reduction in speed. The control is fairly good. The bottom records were made by a most untalented pupil and show, vividly enough, the spread of tension. In this case the entire body was rigid and a tremendous energy—totally misdirected—was used. The speed, on account of the incoördination, naturally was low.

The spread of tension with speed, however, is not in itself an incoördinated movement. The velocity of the moving hand is greater than in slow movements, hence its force is greater. But since intensity is supposed to remain constant, this additional force must be counteracted by appropriate contraction of the antagonistic muscles just before tone-production. Such contraction in turn must have a fulcrum from which to act upon the hand. And this fulcrum to meet the additional force, must be fixed to a greater extent than before. The spread of muscular contraction is, consequently, greater. The difference is not in the turn from *descent* to *ascent*, because, in any real staccato, this is supposed to be as

short as possible. It is in the rapid reversal of direction from *ascent* to the following *descent*, which, in a single staccato stroke, is not necessary.

In a single staccato stroke the contraction of the muscles for hand-lift may take place to any extent in order to insure shortness of tone. Excess contraction will throw the hand back farther, but since there is no need for a succeeding descent, the greater time required to bring the hand to rest does not interfere with the movement. In tone repetition, however, it is just as necessary to initiate

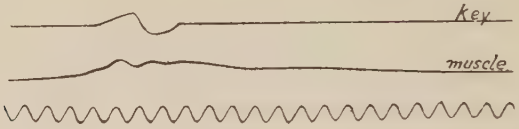


Fig. 97.

the second descent promptly, as it is the first ascent. Inhibition of excess lift, therefore, becomes necessary. By examining a single stroke we can learn when this contraction takes place.

In Fig. 97 the key-movement was recorded by means of a direct lever attached to the key, and the muscular contraction by means of a pneumatic tambour.

The contraction of the muscle begins slightly in advance of key-depression, and at the moment at which the finger reaches the key, the extensor carpi radialis (the muscle primarily controlling the

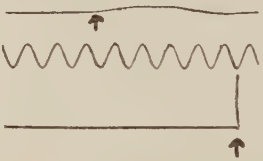


Fig. 98.

hand-lift in hand-staccato) is already partly contracted. The maximal point is reached a moment later, before the key has been actually fully depressed. The time-line is in fiftieths of seconds.

A similar contraction of the flexor carpi radialis—the muscle initiating hand-descent in staccato—takes place early in the down-stroke (Fig. 98). The muscle contracts, aided somewhat by gravity and is already relaxed before the hand reaches the key, because the rise in the upper line, representing muscular contraction, is as a whole

to the left of the beginning of key-ascent, marked by the lower arrow at the extreme right side of the figure. The duration of this particular stroke, as the time-line shows, was one-tenth of a second.

In staccato touches, therefore, the muscles antagonistic to the actual movement taking place contract during that movement. But their pulls are not equal. The asymmetry present in many reciprocal movements is found also at the wrist. Flexion at this joint is considerably stronger than extension. The force of a down-stroke of the hand is greater than that of an up-stroke. This is as it should be, since the up-stroke has as its sole aim the lifting of the hand-weight, and not the overcoming of external (key) resistance. When the pupil's attention is unduly directed toward ascent, additional force is expended against the restraining tissues on the under side of the wrist, and is wasted energy. It frequently results in an awkward position and movement of the hand, similar to that found in finger-staccato when the attention is directed to the finger-lift instead of finger-descent.

Vibrato

A very fast succession of staccato movements, more especially in the louder dynamic degrees, constitutes what is known as the vibrato touch. As a rule, this touch can be sustained for a short passage only, the reason for which we shall see in a moment. The characteristic feature of this touch-form is the state of hyper-tension in which the wrist and arm are held. By simultaneously contracting the extensors and flexors of the wrist the carpal bones are pressed upon the distal ends of the radius and the ulna. The hand thus becomes a unit with the fore-arm, and its weight as a separate unit is withdrawn from the keyboard. The mechanical arm illustrates this nicely; by appropriate contraction of the strings acting as muscles the hand may be maintained in the air in a horizontal direction (opposing the action of gravity) although the wrist-joint (set-screw of the mechanical arm) be itself relaxed. Any "give" at the wrist-joint would, in the touch-form we are here considering, interfere with the speed of movement. This interference may be illustrated by moving rapidly up and down a rigid stick held in the hand, and then doing the same thing with a stick of equal length but hinged in two or three places. In the latter case the variation in force-direction resulting from the spatial displacements of the various parts, makes both speed and accuracy impossible. The degree of this awkwardness depends upon the degree of relaxation in the joints. Here, then, we have a touch-form that demands utmost rigidity for its proper execution.

One use of this touch-form is with bent elbow and abducted humerus, in which position movement of the hand results *not* from elbow movement, but from rotation of the upper arm (see vertical movements). This rotation is axial, that is to say it occurs around the humerus itself as an axis. The centre of gravity of the moving part is thus displaced from hand to a point close to the elbow. This joint region and the upper arm make up the heavier part of the moving arm, the tapering fore-arm and fingers make up the lighter part. At the same time the contraction of the entire muscular

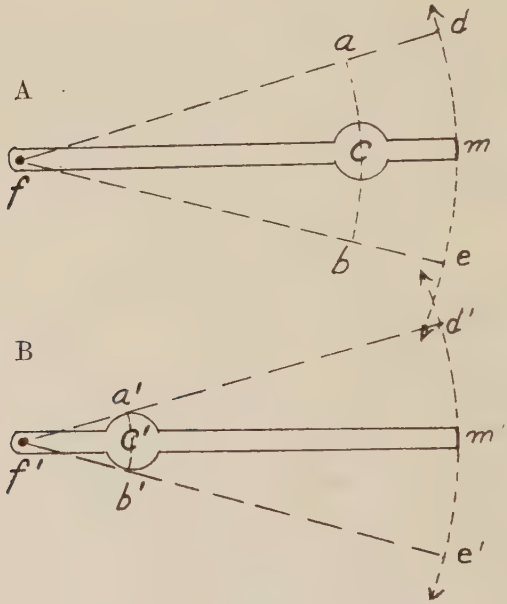


Fig. 99.

system of the arm fixes this to some extent in the shoulder, thus counteracting, to that extent, the action of gravity. This is necessary, because in vertical movements arm-descent is in line with the action of gravity whereas arm-ascent is directly opposed to it. The weight of the arm, and the distance of its normal centre of gravity from the shoulder are sufficiently great to make this alternating action a serious interference with the speed of the movement. The mechanical principle involved may be illustrated as follows : A, Fig. 99 represents the arm-mass in its relaxed form ; B, its mass in the vibrato fixation. In both cases *f* is the fulcrum, and

c represents the centre of mass. The difference in the length of fc and $f^1 c^1$ shows the difference in efficiency for executing a rapid movement in the direction of the arrows. In the first figure in order to move the point through the distance d-e, the centre of mass must be moved through a-b ; in the second illustration, to move m^1 through an equal distance d^1-e^1, the centre of mass needs to be moved only through a^1-b^1. Hence less work is done.

If fixation actually occurs, we shall find when we record the muscular contractions for this touch-form that both flexors and extensors, in the case of a hand-staccato, and both forward and backward rotators of the shoulder are in simultaneous contraction. Otherwise we could not speak of fixation. Moreover this contraction is a necessary conclusion from the analysis of the staccato stroke described earlier in this chapter. There it was shown that the muscles controlling hand-descent were contracted while the hand

Fig. 100.

was still ascending and those controlling hand-ascent were contracted while the hand was still descending. If the repetition of stroke be very fast, the two will of course overlap, and we have what may be aptly described as a voluntary tetanus.

Fig. 100 shows the contraction of the two muscles controlling wrist flexion and extension. The figure was a series of five staccato touches in very rapid succession and at *forte* intensity. The curves should not be read for comparison of the small fluctuations at the crest of the lines, because I could not be sure that the pneumatic recording device did not permit some play. The salient feature, however, of the simultaneous contraction of both flexors and extensors is seen clearly in the deflection of both lines, which occurs at the same time.

The presence of muscular fixation may also be shown by recording the contraction of either extensor or flexor and at the same time recording the movement of the piano-key. The result is given in Fig. 101, which shows the contraction of the extensor carpi radialis (the muscle primarily concerned with lifting the hand in staccato) during a series of five vibrato octaves, played, of course, at a very rapid tempo. The movement of the muscle was recorded by means

of a pneumatic tambour, that of the key by a direct lever attachment with slight magnification of amplitude and reversal of direction. A rise in the muscle-line indicates muscular contraction, a rise in the key-line indicates key-depression. The five staccato key-movements are very marked, and the key returns its full distance between each stroke since the troughs go to, and even below, the

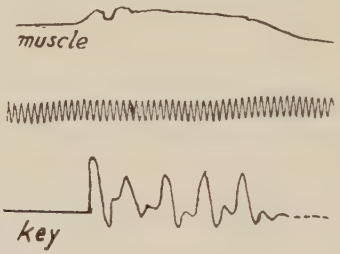


Fig. 101.

stationary key-level shown at either side by the horizontal stretch of line. The time-line shown in the middle is in fiftieths of seconds so that the strokes followed each other at approximately one-tenth of a second. The muscular contraction on the other hand, does not show the separate strokes. Instead, it remains almost at a uniform degree of contraction throughout the five hand-ascents and hand-descents. The partial relaxation shown between the first and second strokes (the lines should be read from left to right) may result from an incomplete fixation at the beginning of the group, although tambour fluctuation is also possible. The marked difference in the two curves illustrates clearly the continuity of the muscular contraction in the vibrato touch, and the discontinuity of the tonal result. It is an additional example of the lack of agreement between a muscular condition and the auditory effect. To a non-pianist, not seeing the player, the lightness and the detached character of vibrato octaves conveys no idea of the muscular tension experienced by the player. The reactions of the two will, therefore, differ similarly.

Hand and Wrist Extension.

An interesting variation in muscular activity is found in hand extension with and without curved or flexed fingers. Normally when the hand is extended with extended fingers the true wrist-extensors (extensors carpi radialis and ulnaris) contract very little,

the extension at the wrist being the result of the contraction of the extensors of the fingers which pass the wrist. But when the wrist is extended with curved fingers, the wrist extensors contract noticeably. Thus staccato octaves played with extended fingers are produced by a muscular contraction different from that for staccato thirds or sixths, where the fingers are well flexed. If the movement be made with the finger extensors primarily, their contraction must be accompanied by a simultaneous contraction of the wrist-flexors, to keep the wrist from sinking. (It is the opposite of the condition described for finger-stroke on p. 218.) This is a coördination among false antagonists, since the true antagonists of the wrist flexors are the wrist extensors. The feeling of strain and fatigue, characteristic of first attempts at staccato octaves, is the result of doing the hand extension or lift with the finger muscles instead of the hand muscles. By keeping the fingers curved, we at once shift the work to the proper wrist muscles and make it impossible for the finger extensors to act. That is why hand staccato can best be taught in thirds and sixths before proceeding to octaves. The less the fingers are extended the more do the wrist muscles act. It is another instance of where a knowledge of physiology is of practical help to the teacher.

The early onset of fatigue in vibrato touches is the result of the fact that a muscle in a stationary contracted state, without appropriate movement or periods of relaxation, always interferes seriously with the circulation within the muscle, damming up the waste products. The physiologists have shown that the efficiency of muscular action depends directly upon this elimination. In ordinary usage the periods of muscular relaxation following those of contraction offer ample opportunity for the removal of the chemical waste by the blood and thus prevent the onset of fatigue.

Neural Phase.

The advantage of the vibrato coördination is not only in the direct mechanical gain, but also in the greater speed with which the neural impulses can act upon the muscles; an illustration of the manner in which nature gains speed of movement in spite of muscular rigidity.

Assume simultaneous contraction of both forward and backward rotators of the humerus sufficient to move the parts of the arm needed. Let *A* be the forward rotators, the contraction of which, with abducted humerus and flexed elbow brings the hand down upon the keyboard; let *B* be the backward rotators, contraction of

which lifts the hand from the keyboard. Both are contracted sufficiently to move the arm readily, but because both are simultaneously contracted, the force-effect of either is neutralized by the other, and the arm does not move, but remains fixed. A sudden increase in the contraction of *A* turns the humerus forward and brings the hand down. Mere release of this additional contraction causes the humerus to rotate back again, since *B* still remains contracted. Whereupon a second contraction of *A* causes a second hand-descent. In the case of a relaxed arm, stimuli would have to go alternatingly to both *A* and *B* in order to produce contraction. In the state of fixation, on the other hand, the only stimulus is a plus pull on either side but not on both. Thus the number of neural stimuli needed is half of that needed for executing the movement in a relaxed manner. The very small range of muscular contraction needed, on account of the favourable position of the muscles, as well as the power of the muscles themselves (shoulder muscles as compared to finger muscles, for example) make possible an instantaneous transfer of force.

This condition may be experimentally proved by the mechanical arm. For this purpose the cords representing one set of muscles are fixed. When the antagonistic set is then pulled it will have to overcome this resistance before movement can result. Consequently, the force will be greater. As soon as this force ceases to act, the sustained contraction of the fixed set will jerk the lever back immediately. A much more rapid back-and-forward movement may thus be secured than by alternatingly pulling the cords of the antagonistic forces.

To the mechanical proof may be added the physiological. A state of hyper-tension is biologically wasteful ; much of the work done is " wasted work ", so far as the force of the final movement is concerned. Accordingly, we should expect an early onset of fatigue, which is nature's reaction to overwork. And this is exactly what happens. There is no other touch-form so " tiring " as the vibrato, and, as a result, we find its use primarily in very short passages or groups, with muscular rest periods between.

Finally, in the vibrato touch we find the one instance in which we can properly speak of an elastic condition of the muscles. When the additional contraction producing the movement ceases, the body moved returns to its original position by virtue of a force already acting during the time of displacement. This is the basic property of elasticity. It is totally different from the countless misleading applications of the word to key, touch, and arm.

Finger-Staccato

A detailed analysis of finger-strokes, including finger-staccato, is given in Chapter XVII. I include Fig. 102 here, however, because it shows, in a modified form, the typical "vibrato" tetanus that we have just been considering. This figure represents a series of staccato finger-strokes, passing from a moderate degree of staccato to the maximum staccatissimo stroke and back again to a moderate staccato. The recording was done with the recording level of Fig. 29. The arm of the lever rested across the tendon of the common finger extensor (extensor communis digitorum). A relaxation of the muscle of this tendon would result in a drop of the recording needle, a contraction of the muscle in a rise of the needle. As the degree of staccato increases, the drop in the needle decreases, until toward the middle of the figure it is only one-fourth of the original drop in the moderate staccato. The muscle controlling finger-lift, therefore, in staccatissimo effects, remains contracted and does not relax but a little during the down-stroke. Such a coördination is based

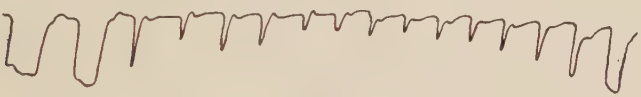


Fig. 102.

upon the gain in speed of reversal of motion which is the redeeming feature of the vibrato touches. The descent of the finger requires an additional force to overcome the resistance of the extensor contraction, but just as soon as this force is released, the extensor lifts the finger without a moment's delay. Moreover, since with simultaneous contraction of antagonistic muscles the inertia of the moving part is decreased (see Fig. 99) the reversal of direction at the moment of finger-key impact is not delayed on account of finger-inertia. Needless to say, the early onset of fatigue functions for the finger-staccato as it does for the hand-staccato or vibrato.

Movement-Phase.

In all staccato touches the positive phase is the hand-release: the up-stroke. It is true that in staccato, as in all touches, tone-production is the aim, but the staccato effect depends not primarily upon tone-production, but upon tone-cessation: a quick "get-away". The attention, as usual, should be directed toward the positive phase, hence the up-stroke. In this connection the staccato

touches are directly opposed to the legato touches, and the importance of directing the attention to the positive phases in both cannot be over-estimated: in staccato the up-stroke counts; in legato, the down-stroke.

Inertia.

In discussing the question of weight-transfer in relaxation, the dependence of it upon arm-position was pointed out, and the conclusion reached (p. 130) that the forward position of the trunk was least effective for weight touch. In vibrato the physiological conditions are reversed. Reduction of useless motion here is a necessary factor. By throwing the centre of mass of the arm very close to the vertical humerus, the inertia of the fore-arm movement is reduced to a minimum. This favours the rapid changes in the direction of the movement characteristic of the vibrato touch, and makes the adoption of a forward trunk-position not only advisable, but even necessary. In fact it is impossible to play an effective vibrato with the arm extended in front of the body. The pianist not only avoids this position, but leans further forward for the vibrato touches than normally.

CHAPTER XVII

Finger-Stroke

In any finger-stroke of piano technique the movement made by the tip of the finger is the determining element, since it is this point that comes into actual contact with the piano-key. The finger itself is a compound lever of three parts, the arrangement of which permits considerable range as to amplitude and direction. Consideration of several typical finger-strokes will help an understanding of the mechanical principles involved. A single finger-stroke is made possible by the fact that the flexor and extensor muscles have four separate tendons each, one for each finger, and the muscle can act as a whole, moving all fingers simultaneously or in any combination of parts. The difficulty which the young beginner finds in separate articulation of the fingers results from the fact that biologically, they are all controlled by one muscle, the coördinated subdivision of which has to be acquired through training. It is not physiologically a fundamental coördination and the capacity to acquire the disintegrated action varies widely among pupils, being one of the fundamental capacities of instrumental talent.

Finger-strokes can differ in only two ways: in direction and in intensity. Variations in direction can take place in several planes, and may be separated from or combined with variations in intensity. Variations of either factor may, again, be of any degree, within the limits set by the physiological structure of the finger, hand, and arm. The classification used in the following pages is concerned with the important typical forms of finger-stroke used in piano-playing, but many modifications are also at the command of the pianist.

Angle of Muscular-Pull.

Before taking up the various finger-strokes, one variant, present to some extent in all finger-strokes, should be mentioned. This is the angle of pull of the finger muscles. When the finger is fully extended, the muscles controlling its descent pull almost parallel to the long axis, hence, at a minimal efficiency. As the finger descends, and changes its angle with the back of the hand, this angle of pull

also changes and becomes more efficient as it approaches a right-angle. Fig. 103 shows these variations diagrammatically. The heavy lines represent the lines of muscular pull, the black segments, the angles of pull, a, b, c, d, e the finger-joints, and a, a', a'', a''' various positions of the extended finger ; *e-f* the central part of the hand. With the finger at a, the line of pull *d-f* is parallel to the line of the hand ; at a''', it pulls at a much better angle.

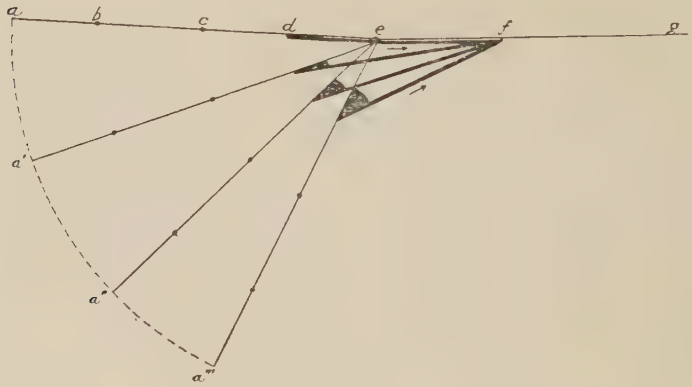


Fig. 103.

Flat-Finger Stroke.

In this touch-form the fully extended finger moves in the hand-knuckle. No movement at either the middle or nail-joint takes place. The distance from the fulcrum to the point of resistance is the length of the extended finger : for an adult third-finger from three to four inches. The length of the vertical arc described by the tip of such a finger is approximately four inches.

A descent of the finger results from contracting the muscles situated in the hand, the lumbricales and palmar interossei. The muscles that bend the two phalanges of the finger are not directly involved. The mechanism is thus a lever of the third class, with the force applied between the fulcrum and the resistance. A lever of this type is of advantage in transferring force into speed. The finger-tip gains in speed but loses in force. The value of the straight finger-stroke, accordingly, is not in the production of loud tones, but of soft tones. If loud tones are thus produced we work at a mechanical disadvantage. Moreover, since the flat-finger position brings the softest part of the " finger cushion " into contact with

the key, the noise of finger-percussion is reduced to a minimum, which, as repeated experiment has shown, is particularly desirable in the production of "singing" tones.

Conversely, if we wish to strengthen the finger muscles by practice, the flat-finger position will exercise them more than the curved-finger position, since they work at a mechanical disadvantage, each stroke requiring relatively more energy. The force of the descending finger is the product of its mass and its acceleration. Since it takes time to set any body into motion, the force with which the finger-tip reaches the key will be determined, in part, by the distance through which it has moved. A high finger-stroke will produce a louder tone, other things equal, than a low finger-stroke. This relationship can, of course, be reversed by sufficient differences in the speed and force of muscular contraction, but in the present analysis, these are supposed to be constants. A high finger-stroke, however, is not adapted to speed of tonal succession since it takes more time to move the finger through four inches and back again, than through two inches. This effect of range on movement we have already discussed in Chapter XII. Accordingly, any passage demanding moderate intensity and great speed, if played with flat fingers, is being played at a decided mechanical disadvantage, and can be more easily and hence effectively played with curved fingers. The advantage of the flat-finger stroke, since its particular characteristics are lightness and minimal noise of percussion, is therefore in "leggiero" and soft "cantabile" passages.

The mechanical effect of a constant muscular pull does not remain a constant. With the finger fully extended, the muscle pulls at a decidedly weak angle since it is pulling almost parallel to the line of the lever itself. As the finger descends, this line of action changes and increases in efficiency as it approaches a right angle with the line of the lever. It seems, therefore, inadvisable to oblige a child just learning a new coördination, to begin with an excessively high finger-stroke, thus forcing the muscles, the correct use of which is the object of the exercise, to work at the very greatest mechanical disadvantage. It is, mechanically, very similar to developing muscular movement through rigidity—an obvious impossibility. The condition here referred to, is rather strikingly shown in the case of pupils with so-called "double-jointed" hand-knuckles. If the fifth finger, in such an instance, be lifted and curved excessively, it is impossible to bring it down without some relaxation in the extensor muscle and then often only with a perceptible jerk as it passes a straight-angle. The condition in a normal hand, though less pronounced, is very similar.

In the very extended position the muscle pushes the finger against the hand-knuckle, and the resulting increase in friction is pure mechanical waste, so far as the effectiveness of the stroke is concerned.

The path traversed by the tip of the finger in the flat-finger stroke is shown in Fig. 104*a*, and the variations in the angle of pull in Fig. 103.

The Curved-Finger Stroke.

The finger is curved in its three joints so that the nail-joint is held vertically. As the finger descends, flexion in the hand-knuckle increases (the same as in the flat-finger stroke) but decreases in the two inter-phalangeal joints. This coördination sends the tip of the finger through a straight, approximately vertical line. Distance from fulcrum to resistance is approximately two inches. In Fig. 104*b* the player's hand was to the left of the figure.

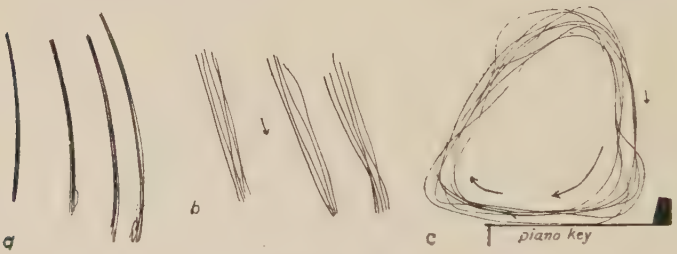


Fig. 104.

This touch-form is the typical curved-finger touch of modern piano pedagogy. Its mechanical advantages may be inferred from the preceding analysis of the flat-finger stroke. Since the resistance is nearer the fulcrum, the effect of the force is proportionately greater. The increase in the noise of percussiveness resulting from the less advantageous part of the finger cushion actually in contact with the key-surface, is partly compensated for by the less amount of actual percussiveness needed to produce the desired quantity of tone. The normal adult curved finger can, if necessary, produce a tone of moderate intensity without any finger-lift from the key-surface.

The physiological forces acting in the two types of finger-stroke are not equal. Since the actual tone-producing part of the finger in all finger-strokes is the finger-tip, the chief determinant of the force effect of the finger-stroke is the distance through which the tip of the finger moves. In a flat or straight finger the finger-tip

in its descent will describe a longer arc than in a curved position, in which the length of the lever-arm is considerably reduced. The apparent advantage of the flat-finger, on account of its greater range, is counterbalanced by the disadvantageous position with regard to force. With the increase in speed goes a loss in force, because the energy is used up in producing speed. It is a condition

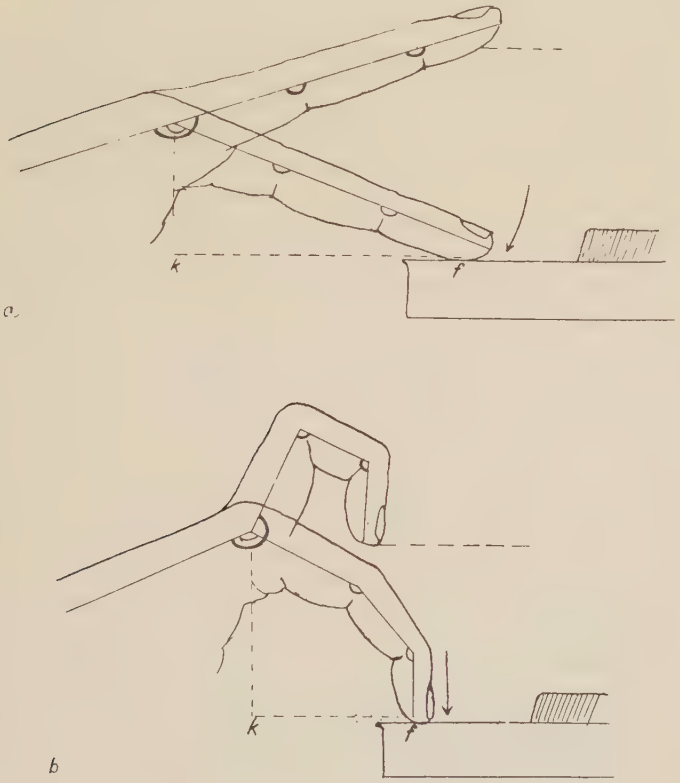


Fig. 105.

similar to that found when we attempt to push forward with the arm fully extended at the side, and again, with the arm sharply bent at the elbow, and held close to the body. The better leverage in the latter case is quite noticeable. This is the physiological expression of one of the laws of the lever stated in the chapter on Mechanical Principles. The relative minuteness of distances here

involved affects the operation of this mechanical law only in the change of absolute values. The principle holds just the same.

We may conclude, therefore, that flat fingers are conducive to speed in finger sequences, curved fingers to force. In a series of earlier experiments I have shown that, normally, we tend to play louder with a curved than with a flat finger, and the records in the preceding and succeeding chapters, dealing with that phase, all show a similar relationship.

Physiological Contrast.

But the physiological differences between the flat and the curved finger-strokes also involve considerable differences in muscular contraction. In order to lift the tip of the extended finger, let us say, two inches above the key, the finger extensors need be relatively slightly contracted.

Then the angle which the dorsal surface of the finger makes with the back of the hand, when the hand is in the normally arched playing-position is, for many adult hands, approximately 200°.

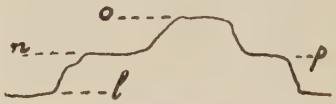


Fig. 106.

In order to raise the finger-tip the same distance, with a fully curved finger (vertical nail-joint) the dorsal angle just mentioned becomes approximately 150°. A general illustration of this difference is shown in Fig. 105 and can be the result only of additional contraction of the finger extensors. It is not the result of the bending, because this is performed by the finger flexors which cannot raise the finger. The same result is obtained when we record the contraction of the finger extensors, by attaching a sensitive recorder to the tendon as it crosses the back of the hand. In Fig. 106, *l* represents the degree of contraction of the tendon when the finger-tip rests upon the key. The tendon here is at normal tension. The recorder was so adjusted that any contraction of the extensor muscle, which necessarily produced a " tightening " of the tendon, caused an upward deflection of the recording point. The finger was then lifted to a position of extension in line with the back of the hand, slightly higher than the position shown in Fig. 105*a*. This contraction is shown by the rise of the line in Fig. 106 to level *n*. The finger was then curved, nothing being said to the subject about

lift. Instead, the instructions were merely to keep the finger ready for a descent. The added contraction of the muscle is revealed by the rise to level *o*, although the tip of the finger remained the same distance above the key. When the finger was returned to its extended, lifted position, the muscle returned to its position of partial contraction, shown by the drop in the line to level *p*, which corresponds to *n*. And when the finger finally descended to the key, the relaxation was complete and the point dropped to its original level *l*. Accordingly, in order to lift the finger preparatory to its stroke, considerably more muscular contraction is needed for a curved finger than for a straight finger, the tip of which is lifted through the same distance.

Moreover, the distribution of muscular forces during the finger-descent differs for the two types of finger-position. When the extended finger descends to the key, the angular relationship among the three phalanges themselves, does not change. The entire joint-action takes place in the hand-knuckle. When the curved-finger stroke is used, however, the finger straightens out somewhat as it descends. The touch thus combines a slight contraction of the extensors of the second and third phalanges and a contraction of the flexors of the hand-knuckle, so that even during descent, there is a slight contraction of the muscles that lift the finger, resulting in so much opposition to finger-descent. The advantage of the curved finger-stroke is in the direction in which the finger finally reaches the key : vertical descent ; a gain not present in the flat-finger touch, in which, if the hand is in the usual arched position, the finger necessarily strikes the key a slanting blow. This difference in the direction of the force is shown by the arrows in Fig. 104*c* and is the type of finger-stroke recommended in the earlier works on piano technique as the typical light staccato touch. Lightness is a necessary result of this touch form since the vertical speed of the finger-tip is considerably reduced as the finger follows the curved line of the arrow. It is but natural, therefore, that such a touch-form should be advocated for light staccato effects. The extension of the second and third phalanges is produced by two sets of muscles : the dorsal interossei and lumbricales, situated in the hand ; and the extensor of the fingers, situated in the fore-arm. In the staccato touch just described, no extension at any finger-joint is present, so that the two types of finger-stroke are muscularly quite different.

The opposition of the finger extensor to the flexor, present in the curved-finger stroke, makes this stroke less favourable for teaching the rudiments of relative finger isolation. The ease of finger-stroke

is much more readily acquired with a flat-finger stroke, and, accordingly, the latter is recommended for the first exercises in finger-stroke. The undesirable breaking-in of the nail-joint is not a result of this finger-position, but of an incorrect coördination, as I have pointed out elsewhere (p. 225).

Muscularly, finger-movement is (as all bodily movements are) not restricted to activity of the muscles directly controlling the part moved. The finger-stroke, under normal pianistic conditions, is accompanied by a quiet arm held in normal keyboard position, well arched hand, horizontal fore-arm at the level of the keys, and moderately abducted upper arm.

The arm and hand-positions thus demanded, as we have seen in the discussion of arm-stroke, involve contraction of the shoulder muscles in order to abduct the upper arm, of the flexors of the

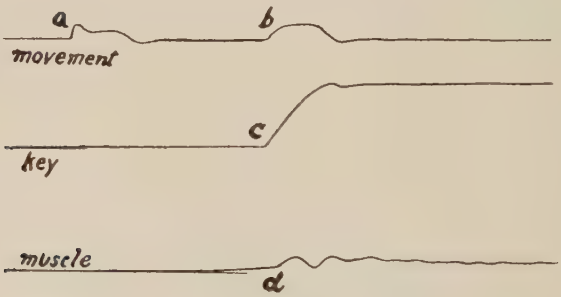


Fig. 107.

elbow, of the pronators of the fore-arm, and of the dorsal flexors of the wrist. The functions of these muscles are, respectively, to keep the arm from sinking against the side of the body, the elbow bent at the proper angle, the fore-arm in a position of horizontal pronation, and the hand in a position over the keys.

As the finger-tip descends the flexors of the hand-knuckle contract, with the extensors of the two phalanges, thus keeping the nail-joint perpendicular and preventing the nail itself, instead of the fleshy part of the finger-tip, from striking the key. When the finger meets the key the resistance would produce upward motion at the hand-knuckle. This is restricted by appropriate contraction of the dorsal wrist flexors. Fig. 107 shows how volar flexor contraction occurs in a full arm-drop. The force of key-resistance thus spends itself against the various fixed joints and these, in turn, enable the descending finger to depress the key with the desired force.

Finally, some contraction of the flexors of the finger-joints is necessary to prevent the " breaking-in " of these joints, especially that of the nail-joint.

The Nail-Joint.

On account of the importance which the " breaking-in " of the nail-joint assumes among the problems of piano pedagogy, a more detailed treatment of this phase is advisable.

In the first place, the normal breaking-in of the joint, as I have frequently mentioned in the case of other joints, is in no way an indication of weakness in the joint itself. It is entirely a question of incorrect muscular contraction and relaxation of the muscles controlling the joint. And, contrary to popular belief, the so-called curved nail-joint position can be best taught from the flat-finger position, not from an exaggeration of the curved-finger position. The reason for this is not hard to find. In discussing the effect upon intensity of the spatial position of the various parts of the skeletal structure involved in the movement, I pointed out the tendency to shift the bones into a straight-line position so that the force would be opposed by a relatively solid bony structure. The bones, in such a case, relieve the muscles from the necessity, and possible injury, of doing excessive work. If the finger-tip be held vertical, its bone, the third phalanx, is forced end to end against that of the second phalanx, demanding very little, if any, contraction of the muscles. On the other hand, in the flat-finger position, the action of the key-resistance (vertically upward) is at right angles to the line of pull of the flexors of this joint (flexor profundis digitorum) and hence the joint can be kept curved only by contraction of this muscle. (Fig. 103 showing the variations in the angle of pull for the first phalanx, may serve as an illustration of this principle, which is similar for the nail-joint.)

Once the pupil realizes that it is a question of contraction of this muscle, the correction of the breaking-in of the nail-joint follows in a very short time. The strength of muscles of children so young as four years is more than sufficient to overcome the resistance of the piano-key. The solution of the problem lies entirely in introducing resistance to the contraction of the muscle and not in a mere curved position of the joint. The coördination is readily acquired by having the pupil place his finger flat upon a black key and then asking him to press firmly while at the same time the finger-tip slides along the key toward the hand.

The device, used by some teachers, of insuring an excessive curvature of the nail-joint by lowering the wrist well below the

keyboard level is better than the curved-finger position, but not entirely good. Unless care be taken to insure muscular contraction, the pressure of finger-tip against the key and the mere weight of the fore-arm, will suffice to bend out the nail-joint. The desired position of the joint is thus secured, but by an incorrect muscular adjustment. The same holds for the curved-finger stroke. In both instances skeletal or tendonous structure holds the joint in position, but the muscles responsible for the position as used in actual playing are largely inactive. Consequently, when the finger returns to a normal stroke, the breaking-in recurs. This argument about the position of the nail-joint is not of purely academic interest. For the position of this joint is physiologically the last joint controlling the transmission of the muscular force to the piano-key. All other parts of the coördination may be correctly adjusted, but if the nail-joint " breaks ", it is not under control, and hence the desired tonal effect cannot be accurately and quickly secured.

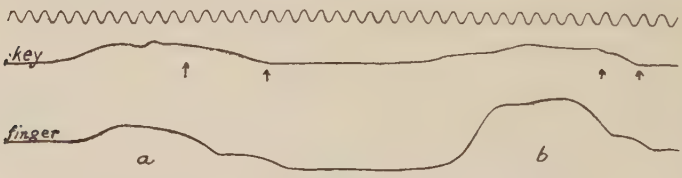


Fig. 108.

The effect of the nail-joint position upon key-movement may be inferred from previous analyses of conditions at other joints. If the nail-joint breaks, the flexors of this joint are relaxed. Hence when the finger-tip meets the key-resistance the key will extend the finger-tip. It is this key-resistance that actually causes the " break ", not any muscular activity. For the joint never breaks until key-resistance is met. The force, then, that should depress the key is being counteracted by the ascending force of key-resistance which in turn bends back the finger. When this extension has reached its physiological limit, a point determined by the range of the tendon and the capsular ligament, the joint becomes a rigid body and the key is depressed. The records of key-descent should, accordingly, show a slower speed when the nail-joint breaks than when it is held partly flexed by appropriate contraction of the deep flexor muscle. In Fig. 108, *a* shows the key-depression for a " breaking " nail-joint, *b* that for a curved nail-joint. The time-line is, as usual, in fiftieths of seconds. By comparing the two curves we find that in *a* key-depression took

five-fiftieths of a second, whereas in *b* it only took two-fiftieths. The imaged tonal intensity was the same; that is to say the velocity of the finger in these records was as nearly equal for both strokes as it is possible for the player to get it.

Finger-Position and Key-Resistance.

The effect of key-resistance upon finger-stroke is likewise determined in part by the position of the finger as a whole. When the key-movement itself is recorded it normally shows a slower descent for a flat-finger stroke than for a curved-finger stroke. (See also Fig. 108.) The reason for this difference is found in the leverage system used. In the straight-finger touch the length of the lever arm is almost twice that of the curved finger, as may be seen by comparing the distances in *a* and *b* of Fig. 105. In my own case the lever in the straight finger (index) is four inches; curved two

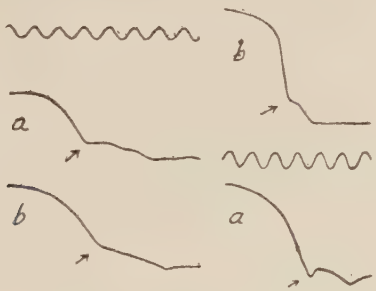


Fig. 109.

and one-half inches. Accordingly, since the forces of two positions are in inverse ratio to the length of the lever arms, the flat-finger touch, other things equal, is approximately three-fifths as strong as the curved-finger touch. The fact that this ratio can readily be reversed through appropriate muscular contraction must not confuse the issue. The same amount of muscular energy will produce a louder tone with curved than with straight finger. Normally we play softer with flat than with curved fingers, and this relationship is altered only when additional muscular contraction is used.

When, therefore, key-resistance is introduced against the descending finger, its effect upon the flat finger will differ from that upon the curved finger. And the nature of this difference we can forecast in advance. Since the key-resistance is a constant for any one degree of tonal intensity, and the force of the flat finger is less than that of the curved finger, the flat finger will be retarded

more than the curved finger, when it strikes the key-surface, and if a greater part of the force of finger is taken up by the upward force of the key, that much less is left for key-depression. In Fig. 109 the two types of finger-stroke are twice recorded. *a* in both sets is the curve for the flat-finger stroke, *b* that for the curved-finger stroke. The point of key-finger contact is marked by the arrows, and the angle formed at this point shows clearly that the flat finger is retarded more than the curved finger. In fact in *a*, in the second record, the finger is actually thrown up for an eighth of an inch before it resumes its descent. In the first set, although the initial speed of the flat finger (*a*) was slightly greater than that for the curved finger (*b*), shown by the greater steepness of *a* when compared to *b*, the retardation is again more marked in the flat-finger stroke. The difference of course in both time and intensity is slight, but just these minute differences are the basis upon which subtle effects of artistic shading so often depend.

Moreover, the elimination of this retardation as far as possible, should be the aim of finger-stroke pedagogy. Such retardation (shown by the complete cessation of descent in *a* of Fig. 109) directly affects the control of tonal intensity. The elimination is secured by appropriate muscular contraction at the moment of impact, the additional force serving to overcome the suddenly added key-resistance. The details of this coördination are discussed in the various touch-forms yet to be considered.

The Elliptical Stroke.

In both types of stroke, thus far considered, the up-stroke is geometrically, but not physiologically, the exact reverse of the down-stroke, the finger-tip traversing the same arc or line in reverse direction. (See Fig. 104, *a*, *b*.) Such a curve, Fig. 104 *a*, (see Geometrics) is characteristic of movement at only one joint. A third type of stroke, met with in the older works on piano technique, is that in which the finger-tip is drawn in as it descends and the tone is made, and returns in a more flexed position of the finger-tip to its original starting point. The finger-tip actually describes an approximate ellipse or triangular path in this case, hence I have called the stroke elliptical. The motion is illustrated on a much larger scale by the "pawing" motion of a horse. Since the angle at which the finger-tip strikes the key-surface approaches a right angle, and the greatest force-effect is at a straight-angle, the elliptical stroke is useless for strength. Its value lies in the extreme lightness with which the key may be depressed, and the finer control of the piano and pianissimo degrees of tone. This control

results from the greater distance through which the finger remains in contact with the key before the key reaches its key-bed. The actual distance of vertical key-movement remains the same of course, being approximately three-eighths of an inch. And when the finger descends vertically, its line of contact is likewise three-eighths of an inch. But when the finger-tip is pulled toward the hand as the key is depressed, its line of contact is considerably lengthened. Experiment has shown that within certain limits this increase is favourable to finer control of speed and resistance.[1]

In itself, that is to say, applied to a single finger, the elliptical stroke is not adapted to speed, since whatever the long diameter of the ellipse described, the circumference is longer than the straight line stroke of the same height, hence, other things equal, consumes more time. However, when fingers are changed there is one form of finger-pattern particularly suited to this touch: the rapidly repeated tone. The movement of the finger-tip used in this type of touch is shown in Fig. 104*c* in connection with the flat and curved finger-strokes

A curious application of this touch-form to all forms of repeated tones, regardless of tempo, will be recalled by every experienced teacher. Yet, neither mechanically nor physiologically is a change of finger desirable when the rate of repetition is slow: Mozart's D minor Fantasia (measure 19), and Chopin's B minor Prelude, right hand, are examples.

Finger-Key Percussion

On the physical side all variations in key-movement group themselves into two classes: those produced by variations in key-speed and those produced by variations in the percussiveness. In the former, the key is set into motion by starting the descent of the finger at the key-surface; in the latter, the key is struck a blow by the descending finger, which has already attained a considerable velocity when it reaches the key-surface. It is natural to suppose, then, that similar conspicuous differences exist in the physiological aspect of the finger-key percussion, for we have seen that the physiological response is determined directly by the mechanical demands of the movement.

When a moving body meets a body at rest there is a mutual rebound, one from the other, the exact ratio depending upon the actual force and upon the masses of the two bodies. When the

[1] O. Ortmann: "Weight Discrimination as a measure of Technical Skill in Piano Playing," *Jl. Comp. Psych.*, vol. iii, No. 1.

finger-tip strikes the key the latter is driven away for a brief part of its descent. Meanwhile the descent of the finger must in consequence be retarded, and for a moment the finger is not in actual contact with the key-surface. When the shock of the percussion has been overcome, the finger " catches up " again with the key and depresses it to the key-bed. The dimensions of this discontinuity in finger and key-descent are so small, and the time required for the complete stroke is so short that neither the eye nor the touch-sense perceives them. Finger-movements, however, may be graphically recorded and fine variations in speed and direction shown. This enables us to study the nature of percussive-touch.

Fig. 110 illustrates one method of recording these movements. The apparatus consists essentially of five non-flexible strips of aluminium attached at one end to five writing levers. By changing the points of attachment to the levers the movements may be magnified or reduced. The other ends of the writing levers touch the surface of a revolving drum. Its movement is horizontal while that of the levers is vertical. Hence speed variations will be measurable by the amount of deflection from the vertical. The lower end of the rods is attached to that part of the finger, the movement of which is to be recorded, care being taken to eliminate " play " in the point of attachment. The entire apparatus must be nicely adjusted so that no appreciable mechanical resistance is introduced.

The direction relationships between finger-movement and drum record will be reversed in such an arrangement. In all the subsequent figures, however, in order to make the reading of them easier the direction has been re-reversed, so that the lines of the figures show the actual direction of finger-movement, a descending line representing a descending finger, and vice versa. No attempt has been made to keep the scale at 1 : 1 or at any other constant since the absolute distance traversed by the finger is of no importance for the conclusions here drawn. Wherever it does influence the result, the scale of reproduction accompanies the figure.

In order further to facilitate the reading of the figures I append some typical curves with their legends. Each figure is to be read from left to right.

a = quick beginning and uniform speed.
b = slow beginning and gradual increase in speed of key-descent.
c = great and uniform finger-speed.
d = slow and uniform finger-speed.
e = increase in finger-speed half-way through stroke. Then a retardation, followed by a subsequent uniformly slower finger-speed.

Fig. 110. Method of recording key-movements and vertical finger-movements.

[*To face p.* 230

f = increase in finger-speed ; then a momentary stoppage of finger-descent (shown by the short horizontal portion of the curve) ; then a subsequent increase in finger-speed to the bottom of its stroke.

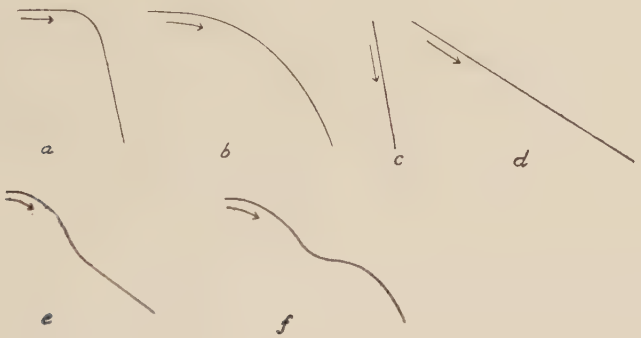


Fig. 111.

Percussive and Non-Percussive Touch.

From a mechanical and physiological standpoint, the difference between these touch-forms may be described as the introduction of a sudden resistance during the course of finger-descent. In non-percussive touches, the key-resistance is present at the beginning of finger-movement ; in percussive touches the key-resistance is not met until the finger has begun and has passed through a part of its descent. The resistance of the key will slow down the finger, since a part of the force of the latter is utilized in setting the quiet key into motion. More force is required to do this rapidly than slowly. The upward action of the key and the downward action of the finger are opposite and equal forces, if allowance be made for the speed of and direction of key-movement. In the middle region of the piano, key-resistance varies from a minimum of approximately two and one-half ounces in the treble, according to the place at which the key is depressed. If the force of the finger is greater than the resistance of the key, the latter will be depressed. If not, the finger-descent will be stopped and the key will remain unmoved. In all finger-strokes we have seen that the immediate fulcrum is the hand-knuckle. Accordingly, this joint must be fixed sufficiently to withstand the key-resistance. Now the fixation of the hand-knuckle depends, in turn, upon the fixation of the hand itself,

which demands contraction of the muscles controlling movement at the wrist. Only by fixing the wrist can the hand-knuckle be held firm. The moment movement occurs in the wrist, movement in the hand-knuckle follows if the finger-position is to be retained. Or, generally stated, the fixing of the position of any joint in which movement is to take place, demands the fixation of all other joints between it and the trunk sufficient to overcome the resistance. For very light finger-strokes, the weight of the hand, and through this, its inertia, may be sufficient to overcome the slight key-resistance, without appreciable fixation of the wrist-joint. But if a louder tone be desired, a fixed fulcrum from which the finger-stroke acts can be maintained only by sufficient contraction of

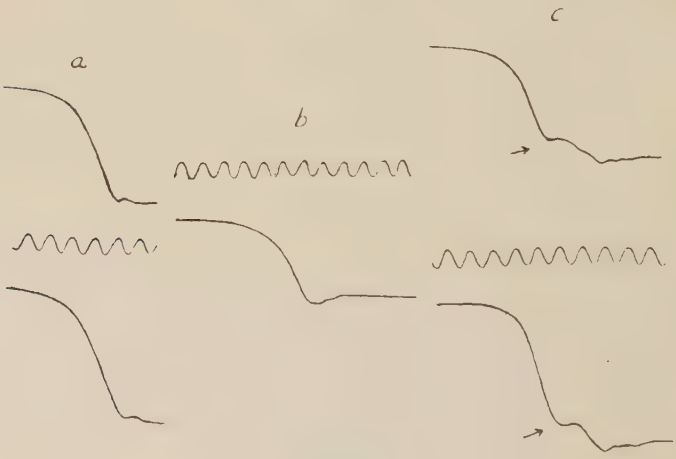


Fig. 112.

muscles controlling the wrist-joint, and for extreme degrees, even those of the elbow and shoulder.

The weight needed to produce a barely audible tone in the middle region of the piano keyboard varies between two and three ounces. For tones of moderate and extreme loudness a much greater force is required. The significance of the key-resistance, in actual playing is therefore much reduced. In fact, the inertia of the key is purposely kept small by the manufacturer so that its effect upon the finger-stroke may be minimal. A resistance of two ounces, against a force of several pounds affects it less relatively than the same resistance affects smaller forces. On the other hand, since the strength of the normal finger is limited, we may expect to find some retardation

in all percussive strokes restricted to finger-action. And this retardation, since it results from the percussion, will be absent in the records of non-percussive strokes. Fig. 112*a* shows finger-strokes with the piano-key fully depressed by outside mechanical means, before the stroke is made. The line descends unbrokenly, and in these records there is no increase of speed after the first third of the movement has been completed. The slight irregularity at the bottom of the curve results from the shock of finger and key-bed percussion. Fig. 112*b* shows the finger-stroke for a non-percussive touch, but without the piano-key depressed in advance. Here, too, we find no irregularity during the finger-descent, since the resistance encountered by the finger is a constant factor. Fig. 112*c* represents percussive touches, and shows clearly the retardation in finger-descent at the point where the finger meets the key (indicated in the figure by the arrows). Moreover, the rest of the curves, after finger-key impact, since it deviates farther from the perpendicular than the parts before impact, shows slower speed. Therefore, the impact of the finger against the key results normally not only in a momentary immobility of the finger, but also in a slower descent afterwards. Several players, after making the records would not believe that the finger had been retarded. They then endeavoured in advance of the stroke to eliminate the retardation, but so long as a finger-stroke was used and the percussiveness was marked, the retardation was present each time in spite of all attempts to eliminate it.

In order to make sure that the particular method of recording did not influence any salient features of the curve, records of the percussive and the non-percussive finger-strokes were also made with a standard form of Pantograph. This method is somewhat less refined than the other, but still the curves obtained, clearly show the retardation of the finger-descent which characterizes all percussive finger-strokes and its absence in the non-percussive touches. Records of the movements of the piano-key,[1] moreover, agree entirely with these variations in finger-movement.

Finally, there is a marked difference in the adjustment of forces in key-depression between a percussive and a non-percussive touch. In a percussive touch the original force can never be maintained because the finger, through the principle of action and reaction, is retarded with the same force with which the key is accelerated. There is, accordingly, a loss in force, for the moment after impact, whereupon the finger reëngages the key and uniform

[1] *The Physical Basis of Piano Touch and Tone,* op. cit.

or controlled pressure is used from this point on. No such adjustment is present in non-percussive touches.

The difference is seen in Fig. 113 in which *a* represents a non-percussive, pressure touch, *b*, a percussive touch. A rise in the line indicates an increase in force, a drop indicates a decrease; a horizontal displacement indicates a maintaining of a constant force. In the percussive touch there is the initial maximum, then a momentary loss, then a uniform force. In *a* the force is steadily gained, and there is no subsequent loss.

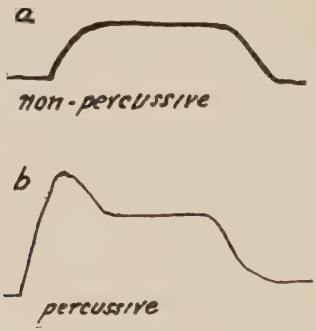


Fig. 113.

Effect of Intensity on Finger-Stroke.

Force is represented by the product of the mass and the acceleration. The former, for any one finger is a constant, the latter, a variable. The value of the acceleration at any point is determined by the degree of positive or negative acceleration and by the initial velocity. In a finger-stroke, starting from a point of rest, the final acceleration at the tone-producing point (the point of escapement) is determined by the speed with which the resting finger can be brought into motion. This consumes time, even though the amount be very small. Consequently, by starting the finger sooner, we gain time before it reaches the escapement point. But if at the same time the distance through which the finger-tip moves remains the mere one-quarter inch of key-descent we lose force proportionately, since a slower beginning with equal acceleration will show less final speed. In order, therefore, to make the increase in time of finger-movement (including ascent) serviceable for most degrees of tone-production, the distance through which the finger moves must be increased. That is to say, if the finger rests upon the key-surface, and a tone of *forte* character be desired,

using primarily a finger-stroke, the finger will have to be jerked back from the key-surface, in order to permit a range of descent sufficient for gaining the necessary speed.

Fig. 114 shows that this actually occurs in such finger-strokes. $a = pp$; $b = p$; $c = mp$; $d = mf$; e and $f = ff$. In the softer dynamic degrees this tendency to lift before the stroke is either absent entirely, or present to a small degree only, since the necessary speed of finger-stroke can be attained in the vertical distance shown. As the dynamic degree is increased the preliminary extensor-thrust increases in proportion, so as to give a greater range of finger-motion before the piano-key is reached.

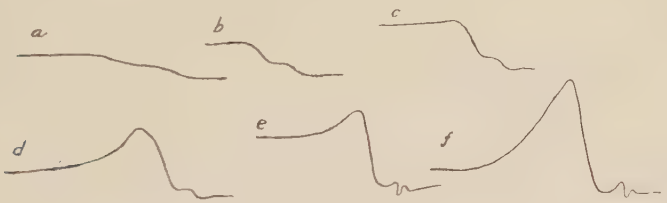


Fig. 114.

Finger-Lift.

It is this extensor-thrust probably, that has been responsible for the adoption of "lifted" finger pedagogy. But, unfortunately, I believe, a necessary distinction between its value for loud tones and its uselessness for soft tones is not always made. Lifted fingers are often insisted upon regardless of the degree of tone-value. The records here shown fail to reveal any trace of this lift when recorded under actual playing conditions for the softer dynamic degrees. The playing was done by experienced pianists unfamiliar with the purpose of the recording. Nor can any need for it be shown on mechanical principles. The excessive, or even any high finger-lift for the production of soft tones is, therefore, clearly a waste of energy.

In this connection it is interesting to watch the playing of any concert pianist at close range. The unused fingers are held—not inches, or even half-inches away from the keys—but almost touching them, leaving just space enough not to move the undesired keys. The narrow spaces by which the hand and fingers escape touching these shows the extreme nicety of well-coördinated movements.

But the effect of a constant high finger-lift carries over also into the wrist, because extreme finger-extension is linked with

dorsal flexion of the wrist. That is to say, with the drawing back maximally of the fingers, goes a tendency to bend back the hand at the wrist. (See p. 43.) But such a bending-back is undesirable for hand-position and the subsequent descent of the finger. Accordingly, the volar flexors of the wrist are contracted in order to overcome this movement at the wrist. The result is a fixing of the wrist to a degree of rigidity out of all proportion to the tone-value to be secured. This stiffening of the wrist is characteristic of piano pupils at the beginning of instruction when extreme finger-extension is insisted upon. The spread of tension, however, is not to be considered an incoördinated response with the blame resting on the pupil. Quite the contrary. Excessive contraction of the extensors of the fingers is normally demanded only to overcome great resistance, such as in lifting a considerable weight hanging from the finger-tips. But if the fingers are to lift this weight there must be a fulcrum from which they can act. This fulcrum is the hand-knuckle, the position of which is fixed by the simultaneous contraction of the flexors and extensors of the wrist. Without this fixation the weight could not be lifted by the fingers. When, in piano practice, the fingers are lifted excessively the capsular ligament, tendonous extension and the fleshy parts around the joint combine greatly to increase the normal resistance, and the neural organism, being faced by such a condition contracts the necessary other muscles in order to overcome the resistance. It is a mechanical necessity that it does so. To insist upon extreme finger-lift and at the same time a relaxation of the wrist-controlling muscles is contrary to both the physiological and the mechanical principles involved and is a coördination extremely difficult, when not impossible, for the beginner to acquire.

Extreme finger-lift, therefore, if it reaches pressure against the restraining ligaments and tissues, involves a fixation of other joints, noticeably the wrist. It follows that, if relaxed movement be the pedagogical desideratum, the pupil should avoid extreme finger-lift. This is but another illustration of the principle that relaxation and extreme range of movement are physiologically and mechanically opposed. Movement is most free when the joints involved move near the middle of their ranges.

Spread of Tension.

The effect of intensity on finger-lift has already been mentioned and the correlation between high finger-lift and loud tone pointed out. The spread of tension into the wrist occurs with finger-descent also since, here too, the excessive finger-lift is used as a means for

securing greater finger-momentum—hence louder tone. And its effect upon relaxation is likewise the same. So that, in the early stages of instruction, where relaxed movement is the problem, tones of minimal or at most moderate intensity should be called for, and the forte and fortissimo degrees avoided. As a matter of fact the stiffness for these extreme degrees never vanishes, at any time of study. We simply cannot play loudly and be relaxed to any extent. The mature artist still needs rigidity sufficient to balance the force necessary for production of the desired tone, and if to the casual observer the condition appears to be one of relaxation, this is because the experienced player, when there is no need for further tension, relaxes immediately after tone-production. (See Fig. 38 in the chapter on Coördination.) The time interval is but a very small fraction of a second and readily escapes detection. The inexperienced pupil, on the other hand, often initiates the stiffness too soon and retains it after tone-production, at which points it has no value. (See Fig. 41.)

Since the spread of tension, which for the purposes here described may be considered stiffness, varies directly with intensity, the least intensity will be accompanied by the greatest relaxation, and may be used in teaching relaxation. In fact, my own experience has been that, by avoiding key-pressure entirely, merely lifting the finger from, and dropping it to the undepressed key, the so-called isolation of finger-stroke, with its resulting relaxed wrist and arm, is more readily acquired than by demanding tone-production, with its necessary muscular resistance.

We find, then, that for all finger-strokes beyond the soft degrees, some muscular fixation of the wrist is necessary. For the loud degrees, this fixation is accompanied by elbow fixation as well. The spread of tension is a necessary mechanical adjustment, without which the finger-tip could not properly act upon the key.

Similar conditions hold for the various finger-joints. The finger as a compound lever, can transmit force through its tip only to the extent that each of its joints is fixed. Any "give" in any of its joints, beyond that balancing the force desired at the finger-tip destroys the efficiency of the lever. (See paragraph on The Nail-Joint.) So the fixation spoken of, applies as well to the finger-joints as to the wrist and elbow. The structure of the finger-joints and their relative positions makes the spread of tension less noticeable here than in the larger joints.

Isolation.

All this points to the fact that isolation applies only to the appearance of a movement and not to its physiological nature,

a fact that should cause us to hesitate is diagnosing pupils' muscular coördination, as is universally done, from the mere appearance, the visible changes during the movement. That physiological isolation cannot exist from a mechanical standpoint I have already pointed out in the discussion of levers and mechanical principles.

Fig. 115.

That it does not exist, physiologically, may be seen in Fig. 115 which represents movement in the upper arm, near the shoulder, for various degrees of intensity in finger-stroke. Beginning with the pianissimo stroke no movement was recorded in the upper arm. A

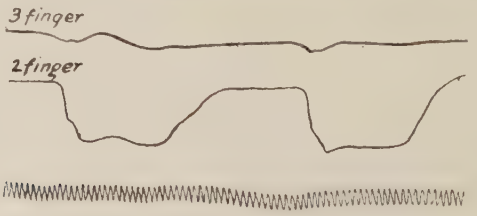


Fig. 116.

slight increase in intensity, however, already shows a reaction of the impact in the upper arm. This is more and more noticeable as the intensity increases, an increase represented in the figure by reading from the top down, six degrees being represented. The record was made by a professional pianist possessing a so-called

" finger-isolation ". All that is needed to show the non-isolated character of physiological movement is a sufficiently sensitive recording device. I am not splitting hairs here, but merely pointing out the fact that isolation is related inversely to intensity.

Fig. 116 shows the effect of a stroke of the second finger upon the position of the third finger. The former cannot move without imparting some of its movement, through flesh and tissue contact, to the adjoining, third finger, the fluctuations in the top line corresponding, in point of time, exactly to those of the lower line. In order to avoid this " sympathetic " movement, pupils are often taught, or naturally adopt, a very fixed hand-position, in which the rigidity of the joints will eliminate the spread of movement. I am not prepared to say just to what extent such practice is necessary, but I believe it is much overdone. At any rate, we must remember that such fixation, since it is not mechanically necessary for the amount of tone produced at the finger-tip, is, according to the definition here adopted, an incoördinated movement, and as such is normally to be avoided. Nor do pianists in actual playing eliminate these sympathetic movements.

Effect of Playing-Unit upon Finger-Stroke.

An indirect effect of intensity upon finger-stroke is reflected in the variations in the mass of the playing-unit. A finger-stroke may be used with a quiet arm, it may be accompanied by a hand-movement, a fore-arm movement, or a whole-arm movement. Each, of course, demands its own muscular adjustment. As we pass from finger-movement to arm-movement we increase the mass of the playing-unit, and, if we assume the velocity of the finger to remain constant, we increase the force of the playing-unit. Consequently, when the finger meets the key-resistance its descent will be interfered with in inverse ratio to the force behind the finger. The finger alone will be considerably retarded, the fore-arm somewhat, the whole-arm little. In experimenting with these variations one must be careful to insure the action of the desired unit: whole-arm, fore-arm, hand, or finger. Otherwise the results will be misleading.

In Fig. 117 are shown the effects of variation in the retardation of the finger-stroke resulting from changes in the playing-unit. In *a* the finger was the playing-unit; in *b* the hand; in *c* the fore-arm with some addition of the upper arm; and in *d* the entire arm. The last named forced a type of arm-movement scarcely practicable in normal piano-playing. I feel, therefore, that the usual arm-weight touch will produce a curve closely approximating *c* rather

than *d*. Since the elimination of the break in the descending line (indicated in *a* and *b* by the arrows), parallels the change in the mass, the weight of the playing-unit is shown to be one determinant of the retardation of the finger-stroke when key-resistance is met. But in discussing dynamics of movement, avoidance of all shock, and continuity of movement were mentioned as the most essential

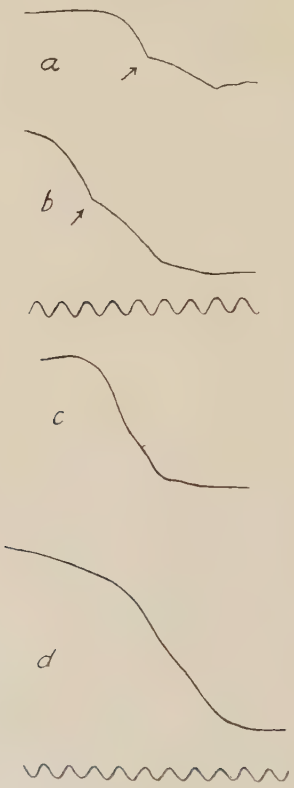


Fig. 117.

features of controlled movement. For maximal key-control, therefore, the use of the arm is to be preferred to that of the finger, at least in the early stages of instruction. Of course, other elements frequently make the application of this principle impossible. Thus speed may make finger-action alone imperative, excluding all arm-movement. I have already touched upon the high degree of key-control possible in slow arm-movement, in discussing

arm-legato. Here the added advantage of eliminating finger retardation and thus transmitting the force without loss to the key is shown. The problem, of course, is correlated inseparably with that of percussiveness; but ignoring the effect of all other factors, the illustrations show that the degree of finger-retardation, and hence of tone-control, is determined in part by the mass of the playing-unit.

Finally, in order to make sure that the records of the finger-stroke were being determined by key-resistance and not by other factors, numerous records were made in which key-movement and finger-movement were simultaneously traced. This was done by attaching a lever to the key played, in addition to the lever attached to the player's finger. A typical record is given in Fig. 118. Between the points *a* and *b* the finger descends through the greater part of its stroke, before touching the key. The latter, of course, remains at rest, as the line *ab* of the key-tracing shows. Between *b* and *c*, both finger and key descend. The greater distance of

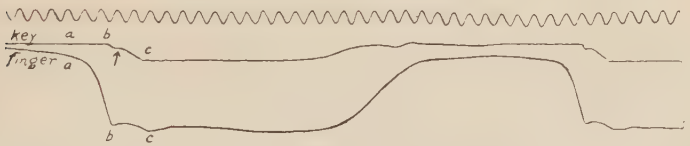


Fig. 118.

descent for the key is explained by the fact that the finger-lever was attached behind the first inter-phalangeal joint, the excursion of which is naturally less than that of the finger-tip, which is further removed from the fulcrum of the movement. But the exact agreement in point of time between key-movement and finger-movement, the beginning of key-descent coinciding exactly with the retardation of finger-descent and the end of key-descent with the end of finger-descent, shows clearly that the records which we have been studying are a safe picture of finger-movement as affected by key-resistance. Moreover, the initial jerk in the key-record of this figure, shows nicely the momentary stoppage of key-descent just after percussion. This point is the short horizontal distance, approximately one seventy-fifth of a second.

Relaxation and Rigidity.

Previous study of the mechanics of relaxation and rigidity revealed the close correlation of relaxation with relative softness and of rigidity with relative loudness of tone. The physiological reasons

for this perfectly natural relationship have already been given in the chapters on Relaxation and Coördination. It will be helpful, however, to note the effect of these muscular conditions upon finger-stroke. In this case relaxation should normally result in a slower finger-stroke than rigidity, for upon finger-speed depends the tonal intensity. In making the records here given, the players were always asked to keep the intensity of the tone as nearly constant as possible. Needless to say this was not always done, since the

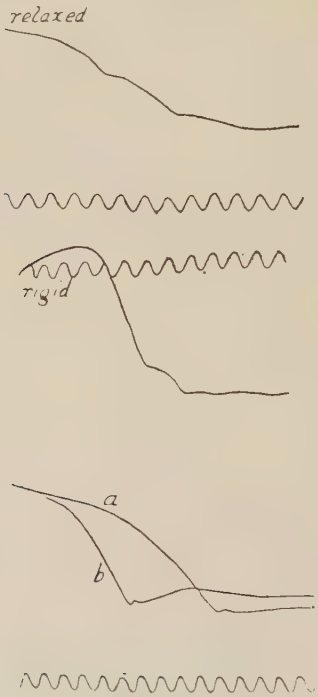


Fig. 119.

difference in muscular coördination robbed the player of a very valuable help in determining dynamic equality. This help is equality in the muscular adjustment itself. To strike equal blows with the finger and then with the arm is much more difficult than to strike two equal finger-blows or two equal arm-blows. The difference between relaxation and rigidity is just as great. A relaxed arm is naturally associated with weak force since it is mechanically impossible to produce a great force with a relaxed arm. And

rigidity is just as closely associated with great force. In fact the scale of tonal intensity on the piano is largely paralleled by a similar scale of rigidity in the player. To ask a player to produce tones of equal intensity with extreme variations in relaxation and rigidity is to ask for incoördinated movement. It is, therefore, not surprising to learn, even when the players considered the movements equal, that in each instance the finger-movement made with rigidity was more rapid, hence productive of a louder tone, than when the movement was made with relaxation. Two pairs of records which serve to illustrate this difference are shown in Fig. 119. They have been selected from many, some of which show less and others noticeably more difference. The direction of this difference, however, never varied. The difference in fractions of a second may readily be calculated from the time-lines given. *a*, in the second group is the finger-movement for relaxation; *b*, for rigidity. Care must be taken, in making such records, that the other determinants of tonal intensity: finger-position, amplitude of stroke, and playing-unit are kept constant.

Tone-Qualities.

One of the most interesting questions, from the musician's standpoint perhaps the most interesting of all, is the effect of finger-stroke upon tone-quality. However fanciful our conception of the artistic phases of piano touch may be, whatever poetic qualities we assign to the piano tone, the fact remains that percussion and intensity are the only determinants. This may be proved readily at any time by anyone taking the trouble to set up the necessary recording apparatus.

All differences in tonal qualities, therefore, must show in the degree of percussiveness and in the velocity of the finger-stroke. The method here used in investigating these qualities was to permit the player to produce whatever tone-quality he desired. The finger-lever attachment then recorded the movement of the finger. Two serious restrictions are thus imposed: movements of any part of the arm other than of the finger are not recorded and variations in the finger-position itself are lost in the record. An extensive analysis of the many qualities that have been assigned to piano touch and tone consequently becomes impossible by this method. But, on the other hand, the extent to which even a partial recording serves to reveal the dynamic principle at the bottom of all tone-production on the piano, is sufficient to permit perfectly safe generalizations.

Let us take, for example, the typical " cantabile " touch, a type of tone-production used in slow, sustained melodies of moderate intensity. If the analysis of the physical properties of piano touch and tone is correct, as a result of which a desirable tone-quality for such a melody is known to be one of little percussiveness and moderate intensity, there should be but little retardation in the descent of the finger. A " surface " quality of tone, as a contrast, is known by experiment to contain a larger degree of noise (percussiveness) and less tonal intensity. In Fig. 120 are seen the curves of finger-descent for both types of tone, *a* being that for the cantabile, " singing " tone ; *b* that for a " surface " or " depthless " tone, a tone lacking in musical quality. Comparison with the curves of Fig. 112*b*, which show the finger-descent when the finger-tip rests upon or very close to the key-surface at the beginning of the stroke, shows that the cantabile touch is one entirely free from

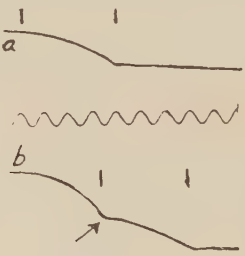


Fig. 120.

percussiveness, since the retardation in finger-descent is entirely absent. In the surface quality of tone, however, shown at *b* Fig. 120, we note a decided retardation (the point is marked by an arrow) as a result of which, in spite of a more rapid beginning of finger-descent, the finger, at the moment of hammer-escapement, is travelling at a slightly slower speed than in the cantabile touch. This is seen by the slope of the lines close to the right-hand vertical dashes. The degree of this difference is too small to be significant, but the fact that the greater initial speed in *b* has been entirely neutralized by key-impact is important. In *a* no force whatever is lost in finger-key impact, and no noise of this impact is present. In *b* the noise is noticeably present and the tone-value is a bit less, or at least is no more than in *a*.

In Fig. 121 are seen the curves for a " good, singing " tone *a*, and a " dry ", musically uninteresting tone, *b*. The markedly steeper curve for *a* means greater velocity of finger, hence, greater

key-speed and in turn, a louder tone. *b* shows very slow finger-speed which is brought to zero for two-fiftieths of a second at the moment of finger-key impact. Again the desirable tone quality is a tone of moderate intensity and but little percussiveness, the latter feature being reflected in the momentary retardation at the middle of

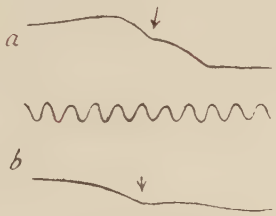


FIG. 121.

descent in *a*. Since the bottom half of this slope slants almost exactly as the top half, the finger has regained its full velocity before the key-bed or even the escapement-point has been reached. This is not so in *b* for the part of the curve after the point of finger-key impact (the line to the right of the arrow) is almost horizontal,

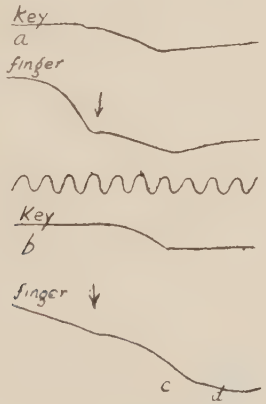


FIG. 122.

whereas the part preceding this point slants. But at the rate at which the finger is moving in this touch-form the tone-production depends upon the part of the curve after finger-key impact. The difference between the slope of this line and the slope of the similar part in *a* is the measure of the difference in the intensities of the

two tones. A dry tone is thus a tone of percussiveness and very little tonal intensity.

Still another pair of tonal qualities are shown in Fig. 122. *a*, a " shallow " tone of good musical quality, *b*, a " full, round " tone. I add the record of key-movement here to show the admixture of arm-movement in the tone of good quality. In *b* the initial descent of the curve (finger-line) to the left of the arrow, and the continuation of the direction, afterwards, with scarcely a fluctuation at the point of finger-key impact (arrow), and its further descent, even after the key has reached its key-bed (the distance is marked *c* to *d*), show the elimination of finger-retardation by the addition of arm-weight and movement. The curve approaches in contour those in Fig. 117*c* and *d*, in which the arm was the playing-unit. The shallow tone, on the other hand, shows a decided percussiveness (the point marked with an arrow in *a*) and a subsequent noticeably slower finger-speed. As a result, in spite of a much greater initial speed (compare the left-hand parts of the descents as to slope) the finger, in the " shallow " tone reaches the point of escapement at less speed than in the " full " tone. Here again, then, the desirable tone-quality was secured by reducing percussiveness and its resulting retardation in finger-movement to a minimum and keeping a sufficient speed for the production of a tone of moderate intensity. The undesirable sound-quality resulted from an undue percussiveness (the auditory resultant of which is noise) and a minimum of tonal value. The break in the actual key-movement, characteristic of all percussive touches, may be seen in the short plateau at the beginning of the descent.

The use of such terms as " dry " and " shallow " may seem far-fetched. However, every player, and certainly every teacher has his or her own adjectives which are applied to piano tone, often very aptly. On the other hand, since the meaning may not be clear to all, I have classified the qualities into desirable and undesirable as well.

The list could be advantageously extended. In many additional records made, none of them disclosed any deviation from the conclusions set forth in the preceding paragraphs. Moreover, the results are in entire agreement with records of key-movement made under similar experimental conditions, and they also bear out the conclusions reached in the chapter on Tone-Qualities, as to the physical basis of tone-qualities.

Repeated Tones.

The adaptation of finger-stroke to the particular character of the technical passage is illustrated in the case of tone-repetition, the

type found for example, in study seven of the Czerny School of Finger Dexterity. The reason for using various fingers for rapidly repeated tones logically follows the analysis made in the preceding pages. By using 4, 3, 2, 1, instead of any single finger four times, we eliminate entirely the need for rapid finger-repetition; the sequence of tones is rapid but since each finger participates but once for every four tones, the rate of finger-repetition is relatively slow. Moreover, the moment one finger-tip leaves the key the next is ready to depress it again. No time is lost in bringing the first finger to a stop and reversing its direction. Accordingly, the value of the changing fingers is in the gain of speed, and for very rapid repetitions, particularly when long sustained, it is the only way in which to avoid premature fatigue. In the discussion of staccato octaves, this fatigue and the means of retarding its onset are treated in detail. Because the change of finger is particularly good, even necessary, for maximum speed of tone-repetition, we should not conclude, however, that the change is good for slow repetition. All editors, it seems, advocate the change, regardless of tempo. The repeated single notes in such compositions as the D minor Fantasia of Mozart, or the D flat Prelude of Chopin, are marked, in all editions I have seen, with change of finger. This is not only unnecessary, but, for inexperienced hands, less conducive to fine tone-control than the repetition of the finger. A study of the effect of a change of finger on weight-discrimination [1] has shown that the discrimination is finest and most accurate when both movements are made with precisely the same parts. That is to say, with as little change in the coördination as possible. Pupils will play such slow repetitions with a much nicer control of dynamic values if they use a single finger instead of a change in fingers for all the repetitions. Only, as pointed out elsewhere, when the tempo reaches a point at which the repetition begins to set up a vibrato fixation, does the necessity for finger-change arise.

Wrist-Position.

Apart from its effect upon the direction of the finger-stroke, the position of the wrist also affects the intensity of the stroke. The inability forcefully to flex the fingers with the hand flexed volarly at the wrist is equivalent to saying that the intensity of the finger-stroke is impaired if the wrist is held high. Any coördination demanding simultaneous contraction of antagonistic muscles (see the analysis of the curved-finger stroke in this chapter) exerts an additional force against the joint, and this force, acting in a direction

[1] Weight Discrimination as a measure of technical skill, op. cit.

usually at right angles to that for which the movement is intended, detracts from the effect of the latter force. Simultaneous contraction of extensors and flexors are present in the curved-finger stroke. The higher the wrist the greater will be the pull of the finger-extensors, when the finger-tip is lifted, hence the greater will be the interference with the downward acting force of the flexors. Moreover, the angle of pull of the flexors is much better when the wrist is low than when it is high. (See Fig. 103.)

Tempo and Finger-Stroke.

In the chapter on Lateral Arm-Movement, variations in tempo showed a characteristic change in the nature of the curve of movement. In slow tempi the arm was not lifted in a continuous arc, as in the rapid tempi, but was transferred at low level with a subsequent rise as preparation of the second down-stroke. (See Figs. 65 and 66 as examples.) The reason given was physiological economy. We should logically, therefore, expect to find a similar

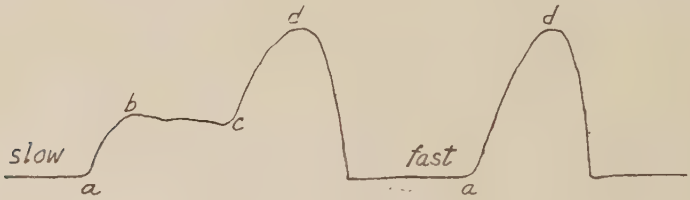


Fig. 123.

condition in finger-movement. When the rate of finger-movements is very slow, it is physiologically wasteful to carry the finger in a high lifted position between strokes. A lift sufficient to permit the piano-key to ascend and thus stop tone, is all that is needed. Such a lift would still leave the finger-tip resting lightly upon, or held very closely to, the key-surface. Just before the following stroke, the finger would be lifted to the full extent desired, descending immediately for its next tone-production. In Fig. 123 typical instances of the two types of finger-stroke are given. In the curve for slow tempo the finger lifts slightly from *a* to *b*, just enough to allow the piano-key to ascend freely. The finger is then poised for a moment or two slightly above key-level, from *b* to *c*, and just before the second stroke, it is lifted to the full stroke height, from *c* to *d*. When the tempo is rapid the lift from the key to the full height, *a* to *d*, takes place at once, and the preliminary resting at a partial lift (*b* to *c* in the slow tempo) is absent. Reference to the

figures illustrating the effect of tempo on lateral arm-transfer in Chapter XIII, show precisely the same difference in the type of movement. We may assume therefore, that we are dealing with a physiological condition characteristic of movement in general, so far as it is affected by variations in the rate of repetition.

The question now suggests itself: should the high finger-lift be demanded in teaching, even at slow tempi? The answer depends in part upon various psychological factors, hence it can only be touched upon here. It seems that if the aim of the exercise be speed, an immediate finger-lift (but not excessively high) and descent are desirable even in slow practice. But if the problem be the development of a free finger-stroke, the high-lift maintained throughout the interval between the strokes is a hindrance, and, as such, is to be avoided. At any rate, in actual playing, the unused fingers are carried close to the keys and not in a highly lifted position.

Mechanics of the Arched-Hand.

The various types of finger-stroke which we have been considering cannot well be dissociated from the position of the hand itself, because this position in turn determines the position of the fulcrum at which the finger-stroke pivots. Modern pedagogy, practically without exception, has adopted the arched-hand position shown in Fig. 16*b* and has given up the flat position of Fig. 16*a*. I have already pointed out some of the physiological advantages of the arched-hand, such as the shifting of normal finger-movement into the mid-range of action. And there is also a mechanical advantage. In the flat hand the muscles are pulling at the least effective angle, shown in Fig. 103 by the approximate parallelism between the top light line, representing the bone axes, and the heavy line representing the muscular pull. In the arched-hand, as the similar lines in Fig. 103 show, this angle has been considerably changed, the muscles now acting at a decidedly greater mechanical advantage. The onset of fatigue is known to be, in part, dependent upon the mechanical efficiency of the leverage system employed. The use of an excessively flat hand-position in order to strengthen the finger flexors by making them work in the least efficient position is not to be recommended. Such a position, if the practice is to do any good whatever, must be maintained by a contraction of the finger extensors, this contraction furnishing the necessary added resistance which the flexors must overcome. The result is a hyper-tension at the hand-knuckle, a typical incoördination which piano technique strives to overcome. Moreover, when the finger

flexors have additional resistance to overcome in normal movement, their increased contraction is never accompanied by an increased contraction of the extensors also, but rather by an increased relaxation. The physiological conditions, therefore, are quite different. If additional resistance be desired for the strengthening of the muscles, this can be secured by appropriate weighting of the keys or by some form of finger exercise with appropriate apparatus, thus approximating the mechanical conditions actually found in playing.

CHAPTER XVIII

Scales

An important part of finger-work on the piano is concerned with diatonic and chromatic progressions. Typical instances of such technique are found in the scales. Not merely the formal complete scales, but any diatonic or chromatic passage demanding a shift of the hand from the first five-finger position. The only muscular difference between a scale and a five-finger passage is in the passing-under of the thumb (for ascending figures right-hand, and descending figures left-hand) and the passing-over of the hand (for reverse directions). Our analysis, therefore, will be concerned primarily with these two phases of the movement, the physiological mechanics of the simple finger-stroke having been discussed in Chapter XVII.

In the chapter on weight-technique the impossibility of transferring weight, when any rapid repetition of finger-stroke is involved, was pointed out. In an ascending scale, right-hand, the lift of the third finger, when the thumb plays, is necessary in order to permit the second finger to play immediately after the thumb. This lift is necessarily accompanied by a lateral shift, without which the fingers could not be brought over their proper keys. The ascent of the finger is thus accompanied by a rolling of the thumb on its longitudinal axis, plus movement in its joints, which shift the hand over the thumb, the position of this digit being fixed by contact with the piano-key. Since finger-lift and hand-shift occur at the same time the third finger itself will describe an approximately straight line ascending to the right. Thereupon it will descend approximately vertically upon the key, for its next stroke, after which the curve will be repeated.

In a descending scale, the third finger plays immediately after the thumb at one point, and after the fourth finger at the other point. The height at which the hand may be held over the keyboard, by supporting it on the thumb-tip is much greater when the thumb is in normal flexion at the side of the hand, than when it is flexed under the hand. Consequently, in an ascending scale, the greatest height will be toward the end of the lateral hand-shift, whereas, in the descending scale it will be near the beginning of the shift. This highest point, however, is influenced further by the

shift itself, which takes place while the hand is lifted over the thumb. The highest point of the curve will, as a result, be shifted toward the centre of the curve in a descending scale.

By attaching a source of light to the first phalanx of the third finger, so that the light stands immediately behind the second finger-joint, the movements of this joint in scale passages may be photographed. The typical curve resulting from this procedure is illustrated in Fig. 124.

In this figure the position of the observer is one facing the player as he sits at the keyboard, with the eye near the level of the keyboard. The observer is thus looking across the keyboard at the hand. The curve *a* shows the movement of the third finger in an ascending C major scale ; the curve *b*, that for the same finger in a descending scale. The difference in contour between the two should be noted, since it will recur in later illustrations as a typical phase of the movements. *a* might aptly be described as a saw-tooth curve, *b* as a scalloped curve. In *a* the crest of the curve is approximately over the descending portion thereof whereas, in *b* the crest is reached almost at the mid-point between descents. Needless to say the curve shown in Fig. 124 as typical, coincides in all the salient features mentioned with numerous other records made and is not the movement peculiar to the particular pianist making the record. The theoretical analysis preceding the illustration shows the mechanical reasons for such a curve, with which it would not agree, were the curve the result only of individual variation.

The curves for the other fingers will naturally differ somewhat from those of the third finger, because the relationship of their movement to the hand-shift is different. I have selected the third finger for illustration because its movements with regard to the thumb are similar on both sides : in ascending scales (right-hand) the second finger is between it and the thumb, in descending scales, the fourth finger, alternatingly.

Of particular moment in scale-playing is the thumb-movement, requiring the passing of the thumb under the hand. The anatomical position of the thumb differs noticeably from that of the other fingers. We may expect, therefore, to find its movement in scales differing also from finger-movements, such as those here recorded for the third finger. In the first place its ascent from the keys is definitely limited by the hand itself in all positions in which it must get beneath the hand. In the second place, contrary to the hand-movement, it is freer in scale-descent (right hand) than in scale-ascent. In scale-ascent it is shifted close to the key-level,

Fig. 124. Movement of the third finger (first interphalangeal joint) in an ascending (right to left) and a descending (left to right) scale. Tempo : *allegro*.

Fig. 125. The movement of the thumb in a rapid scale ; ascent : left to right ; descent : right to left.

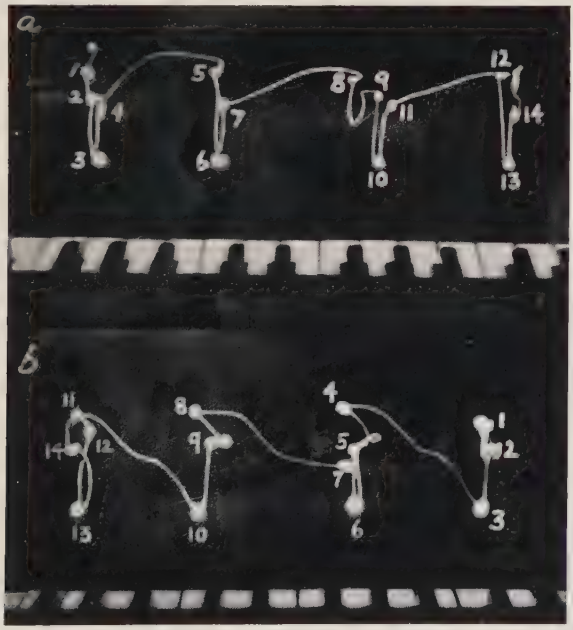


Fig. 126. Movement of third finger in descending (*a*) and ascending (*b*) scale, with full preparation.

[*To face p.* 252

the position of the second finger precluding a higher lift. In the descending scale, this interference with height is noticeable only at the beginning of the thumb-movement; after this point the thumb is no longer under the fingers, and can be lifted amply at the side of the hand. The crest of this movement will thus be reached immediately before descent. A typical thumb-curve in scale passages is shown in Fig. 125. The observer stands behind the player, slightly to the left. The ascending movement, therefore, reads from left to right. Here the curve for descent *b* is very similar to that for ascent in Fig. 124. The curve for ascent *a* is flatter because the hand interposes an obstacle against higher thumb-lift.

Asymmetry.

Before proceeding to an analysis of the effects of intensity and speed upon scale movement, a salient feature of so-called opposite movements in piano technique deserves mention. This point has already been repeatedly touched upon under *asymmetry*. It is more conspicuously noticeable, however, in scale technique. On the keyboard a descending scale is, spatially, the direct opposite of an ascending scale. This has led to the inference that physiologically the movements are likewise opposites. The curves in Figures 124 and 125 prove that this is not the case. The curves for ascent and descent are not symmetrical with regard to any plane: one is distinctly a series of angles, the other just as distinctly a series of curves. The muscular coördination differs accordingly. This is obvious upon even a superficial study of the thumb and hand-formation. Movements of the same parts differ between ascending and descending figures. In this lies the cause for the difference in difficulty experienced by many pupils between ascending and descending scale-passages. In the ascending scale right-hand, the thumb plays most often when under the hand, a position ill-adapted to the thumb-stroke. Contrary to popular belief, it is not the passing-under of the thumb that is difficult but the playing of the key with the thumb held under the hand. The passing-under of the thumb is a flexion action which is present from earliest infancy as a part of the grasping reflex. But the coördination fixed in the nervous system is solely concerned with bringing the thumb toward the hand. When we play it vertically in that position we use it in a direction at right angles to that of this coördination. Any pupil will at once make the passing-under movement if told to touch the base of the fifth finger with the thumb-tip of the same hand. But the learning of the vertical thumb-stroke

under the hand is a far more difficult task. It is physiologically easier when the hand is slightly supinated (the typical slant toward the fifth finger), because the thumb can then be abducted more nearly in a vertical line. That is why the slanting hand is so often recommended for ascending scales in the right hand, and for descending scales in the left hand.

The two distal joints of the thumb correspond to the second and third joints of the other fingers in that they are simple hinge-joints. Consequently with the thumb at key-level, movement in either or both of these joints can produce only horizontal motion at the finger-tip. The vertical movement of the finger-tip demands motion at some other joint. This is the meta-carpal connection, which, in the thumb, is situated very close to the wrist itself. It is normally not detected by the eye and is, accordingly, often overlooked in locating the source of thumb-movement in scale passages. It may be seen in the pictures of the hand shown in Chapter XXII. The movement itself is awkward, being produced by the long abductor of the thumb when this digit is already under the hand, hence in a poor position for further vertical abduction on account of the essentially rotary character of the thumb movement. In teaching the fundamental movements of scale playing, this vertical stroke will demand far more attention—for physiological reasons—than the mere passing-under, although the latter is usually given the greater pedagogical consideration. Exercises requiring the thumb to play while under the hand and separated from any horizontal movement, will be found helpful. The tendency to play the hand by depressing the wrist as a substitute for the desired thumb-action is quite natural and physiologically not difficult. Failure of pupils to put the thumb under promptly in scales is the result of misdirection of their attention, and does not constitute a muscular problem. The vertical stroke of the thumb, especially when this digit is under the hand, is a muscularly awkward movement, serving, from the standpoint of nature, no useful purpose in the life of the organism. The extent to which the passing-under of the thumb is actually necessary in scale playing is discussed under the effects of speed.

Preparation.

In no one field of piano technique is preparation of the next tone or tonal sequence so firmly insisted upon as in scale playing. The prompt passing-under of the thumb and equally prompt passing-over of the hand are diligently practised from the beginning. Each unused finger is held well lifted, often so high that a pencil

can be passed over the finger holding the key depressed and under the two adjoining lifted fingers. The object of such a procedure is to bring each moving part over its next key as early and as quickly as possible, holding it there stationary until the time of stroke. Recording the third finger-movement in this manner we get as a typical curve that shown in Fig. 126. At *a* the scale was played descendingly and very slowly ; at *b*, ascendingly, also very slowly. (The observer is looking across the keyboard at the finger.) The bright points along the curve are the points where the finger remains at rest.

In *a*, for the descending scale, each step, as before, is represented by a stretch of line between two bright spots. Beginning at the left side of the figure, the third finger is held lifted (1) while fifth finger plays ; is pulled down slightly as fourth finger plays (2) ; descends to key (3) ; returns over same path (4) as second finger plays ; remains lifted as thumb plays, and is shifted laterally (5) ; the third finger plays again (6) ; returns over same path as second finger plays (7) ; shifts laterally as thumb plays (8) ; moves sympathetically (small U-shaped part) (9) as fourth finger plays ; descends to key (10) ; returns over same path as second finger plays (11) ; shifts laterally as thumb plays (12) ; descends to key (13) ; returns over same path as second finger plays (14). Beginning at the right end : in *b*, the various parts of the movement are : third finger at rest (1) ; slightly lowered (2), when second finger plays ; third finger descends (3) ; is lifted diagonally as thumb plays (4) ; lowered slightly (5) as second finger plays ; descends again to key (6) ; returns over the same path (7) as fourth finger plays ; is further lifted diagonally as hand is shifted over thumb (8) ; descends slightly as second finger plays (9) ; descends to key (10) ; is lifted diagonally as at first (11) when thumb plays ; descends slightly as second finger plays (12) ; descends to key (13) ; returns over same path as fourth finger is played (14) ; remains lifted as fifth-finger is played.

In interpreting photographs such as those in the preceding figure, the differences in luminosity or brightness between one part of a line and another must be taken into account. The brighter the spot or line, the slower has been the movement at that point ; the fainter the line, the faster did the image of the luminous spot pass over that part of the photographic film.

The finger-movements shown in Fig. 126 represent curves produced when each movement is, so far as possible, prepared in advance. The fact that minor movements are noticeable when other fingers are playing shows again the principle of action and

reaction discussed in an earlier chapter. Although the asymmetrical phases of ascent and descent are somewhat less marked in such curves of preparation than in normal speed curves, they exist, none the less. The diagonal progression in the ascending scale, from 3 to 4 or 10 to 11 in Fig. 126*b* is much more marked than the more horizontal transfer from 4 to 5 or 7 to 8 in *a*. This is of course necessary, since in a descending scale (right hand) the third finger cannot move horizontally until the second finger has played. A similar condition holds for the ascending scale when the fourth finger plays and, accordingly, the curve between 5 and 8 in *b* is very similar to that between 5 and 8 in *a*, with direction reversed. In a descending scale, this lift of the third finger is necessary for each stroke because it is always followed by the second finger. In the ascending scale, on the contrary, the fourth finger playing but once in an octave, the shift occurs immediately at one time (3 and 10), and is delayed at the other time (6 and 13).

Agogic Effects.

The manner in which a scale is played differs with the speed at which it is played. The analysis of the touch-forms already illustrated, as well as the theoretical mechanical principles, leaves no alternative. Speed will affect the nature of any pianistic movement.

In Fig. 127*a* may be seen the line described by the centre of the hand in a very slow ascending scale, C major, viewed from directly above. As each finger strikes the key, a slight rise in the hand-knuckle pulls the hand forward slightly and accounts for the short forward and backward shifts noticeable at the points where the hand is relatively at rest. But the most outstanding feature of the line, from the standpoint of movement, is its relative rectilinearity. If we exclude the shifts just mentioned, we notice that the hand, as a whole, is transferred along the keyboard in an approximately straight line. The motion results, therefore, from a combination of elbow extension and humerus abduction; the elbow is straightened out as the hand advances along the keyboard, and the upper arm is lifted away from the side of the body slightly. But there is no appreciable forward or backward motion of the upper arm.

When the same scale is played rapidly we get a curve like that of Fig. 127*b*. The appearance has changed radically. The straight-line effect is lost and is replaced by a series of forward and backward movements of the whole arm. All points of rest have been eliminated and the movement is both curvilinear and continuous,

Fig. 127. *a*, Movement of the centre of the hand in a very slow, ascending scale; *b*, same scale, played rapidly.

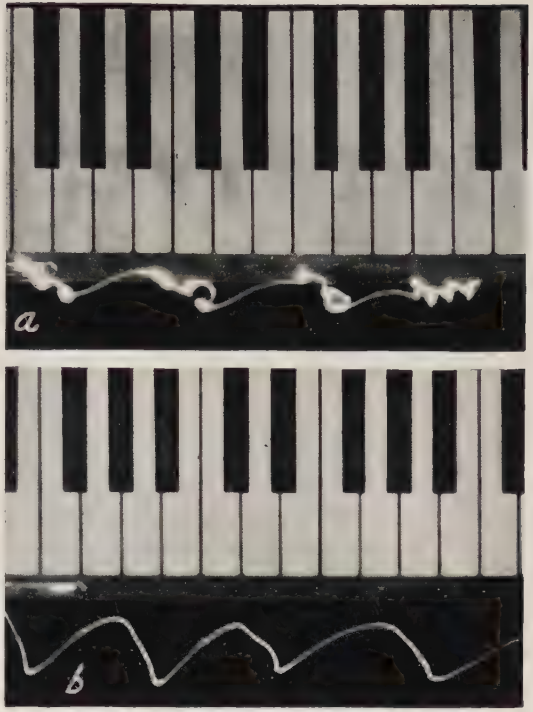


Fig. 128. *a*, Hand-movement in a descending scale, played very slowly; *b*, same scale, played rapidly.

[*To face p.* 256.

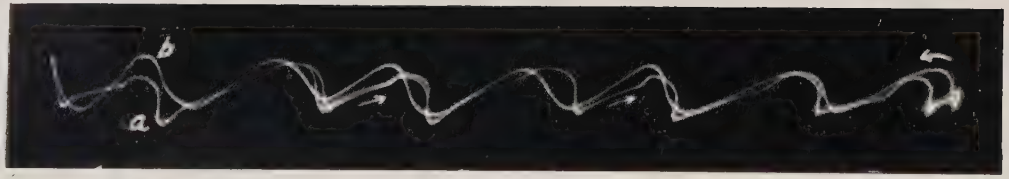


Fig. 129. Hand-movement in a rapid, ascending and descending scale. Viewed from above.

Fig. 130. Thumb-movement in a rapid, ascending scale, showing its passing under the fingers. (Read from right to left.)

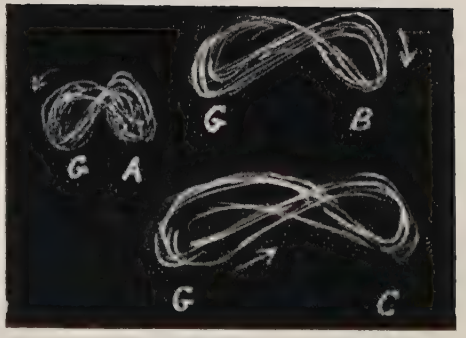


Fig. 132. Effect of range on lateral arm-shift.

[To face p. 257

whereas, in the slow movement it was rectilinear and discontinuous. (Compare this with Figs. 136 and 145, showing lateral arm-transfer in arpeggio.)

A similar result is found when we analyse the descending scale movements. Played slowly and with free arm we get the curve of Fig. 128*a*. Even at the slow tempo the forward and backward shifts of the arm, while the hand is transferred laterally, are readily discernible. This shift is seen in the slant of the line between two bright points, when compared with the line of the keyboard. Comparison with *b* in the same figure, which is a typical curve for hand-movement in a rapid descending scale, shows considerably less difference than that between speed of ascending scales. The reason for this is in the fact than when ascending slowly, the thumb action differs radically from that of fast scales; whereas the difference in the manner of crossing the hand over the thumb in descending scales, does not differ so widely with changes in speed. There still remains, however, the marked difference in continuity; *a* showing the expected points of rest, while *b* shows the unbroken shift along the keyboard. This, of course, is an obvious fact, yet it affects the underlying muscular coördinations very much. In one case finger-action is unaccompanied by arm-shift, in the other case, both phases occur concomitantly. The muscles causing arm-shift are a different group from those causing finger-action. Hence, in a slow scale the muscles acting differ from those acting in a rapid scale. A series of separate movements is replaced by a single continuous movement. If we reflect, now, upon the underlying mechanical principles, we shall recall that each rest point is established by muscular inhibition, and this inhibition is not present in a continuous movement.

When we combine the rapid ascending and the descending scales, we get, as a typical curve-form, that shown in Fig. 129. Comparison with Fig. 127 and Fig. 128 brings out the permanent features of the movement: the two forward shifts for ascent (*a*) with each lateral transfer (reading from left to right in this figure), and the single, slightly more marked forward shift in the descending scale (*b*). The superposition of the two curves shows these differences between the ascending and the descending movements quite clearly. The scale of reduction is approximately as 1 to 6, so that the forward and backward hand and fore-arm shift in a rapid scale, played moderately loudly, was approximately two inches, not a negligible distance in relation to the dimensions of the hand and of the keyboard. The nature of the movement changes of course at either end, where the direction is reversed, and this change is noticeable

already in the forward shift immediately preceding the change. The view is a top view, the point photographed is the middle of the hand. Finger-movements, accordingly, could not influence the outline of the curve.

The fact that in all the illustrations, regardless of speed, some hand shift occurs—in the rapid scales to a marked degree—is interesting in view of the usual pedagogical insistence upon a quiet hand in scale-playing. The forward and backward arm-shift (*b* in Fig. 127 and Fig. 128) is eliminated by such instruction, as far as possible. Yet in each case of rapid or slow scale that I examined, under normal playing conditions, this arm-shift was present. The movement, moreover, is quite similar to that made by talented pupils before they have been taught the quiet hand type. But I am not prepared to say whether or not it is an acquired or more fundamental coördination. This problem is primarily a psychological one. However, I do feel that the teacher frequently, by watching these hand-movements, reads accents and irregularities into the tonal result that actually do not exist. That is to say, the presence of such movements does not necessarily produce an irregular scale. This fact has led several pianists to assert that in a rapid scale the thumb is not passed under at all. This is an extreme view, which, although certainly true to some extent, is an exaggeration of the facts. Fig. 130 is a picture of the thumb-action in a rapid ascending C major scale. In this case the observer is facing the player, hence looks across the keyboard at the hand. The luminous point was attached close to the nail of the thumb. As soon as the thumb passes under the second or any other finger, this finger will fall between the light and the photographic film and will obscure the thumb movement. The keyboard is shown through a considerable range, the centre of which is in direct line with the point of observation. This distance is that between the two short vertical lines. The dotted parts of the curve is the part of thumb-movement during which the thumb is under the other fingers. The extremes of this record cannot be used for diagnosis since the perspective is such that the results would be misleading. This accounts for the greater stretches of breaks at the right side of the figure.

Thus the thumb does pass under the second finger in a normal rapid scale, but the actual amount of passing-under decreases as the speed is increased. In passing under, it never, in any of the records secured, completed its shift while only the second finger played, but covered the distance while the second and the third fingers played. The form of passing-under, practised while holding

the second and third fingers on the depressed keys, is not used in actual playing. It represents an extreme coördination which is opposed to speed. A rapid scale is played with a continuous arm-shift, which is accompanied by a partial passing-under of the thumb. This is verified by the pictures of thumb-movement shown in Fig. 130.

Octave Diatonic Scales

Diatonic scales in octaves normally consist of a combination of staccato touch and lateral arm-transfer. The staccato touch results from the repetition of fingering, the lateral transfer from the shift from key to key. We may expect, therefore, to find the coördination for staccato touch functioning plus the curves analysed for horizontal arm-movement. The range of the latter will, of course, be greatly reduced since it now covers the width of only one piano-key. This combination of hand-movement and lateral arm-shift has already been touched upon and illustrated in Lateral Arm-Movements (Fig. 66, *a*). The loop-form resulting

Fig. 131.

from the asymmetry of the curve remains (compare Fig. 131, with Fig. 66, *d*). Fig. 131 shows an ascending diatonic progression of four keys and a return over the same keys to the starting point. The path traversed is that for the centre of the hand, with the observer in a position behind the player, eye on a level with the keyboard. The agreement of the shape of these curves with that for much greater distances leads to the probability that the same plan of coördination is functioning, even over the small distances. The difficulty of recording the extremely slight muscular contractions needed for diatonic lateral transfer of the arm made it impossible to get records sufficiently definite to warrant their serving as an accurate basis for deduction. Accordingly I should not say conclusively that the " free-body " coördination, in which the arm is thrown through a part of its distance as a relatively free-body, holds for movements of so small a range as the width of a single piano-key. The similarity of the curves, however, seems to indicate that it does. A lateral shift of only one key shows the same loop or bow-tie effect. As the distance increases the curve flattens somewhat, but the asymmetry remains. This is illustrated in Fig. 132, which shows the curves for a rapid lateral arm-shift for the distances given.

Dynamic Effects.

In a heavy *portamento*, taken at a moderate speed, the centre of the hand moves as shown in Fig. 133. The observer is on a level with the keyboard, behind the player. The angularity of the curve means discontinuity of movement, for a continuous physiological movement, with change of direction, is necessarily in curved lines. The hand in a heavy portamento is lifted to the maximum height

Fig. 133.

desired and poises there for a moment before descending upon the next key. This descent takes place in an approximately vertical line. The apex of the triangle is, therefore, not midway between the keys but over the key to be played. (Fig. 133 should be read from left to right.) The mechanical advantage of this is obvious: it enables the force of the descending arm to act in the direction of maximal efficiency, in a direct line with the movement of the piano-key. The intensity is likewise reflected in the height of the movement, which is considerably greater than that for normal diatonic arm-movement.

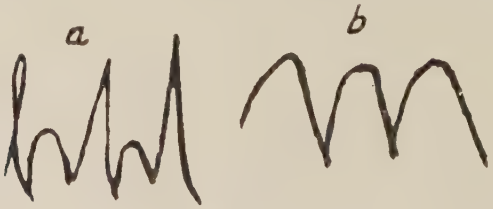


Fig. 134.

In this poising over the key we meet again the factor of spatial preparation. This is by no means an essential feature of the movement. It merely divides the movement into two parts, of which only the second is concerned with tone-production.

The effect of intensity upon staccato octave-scales is entirely similar to its effect upon any staccato touch. As intensity increases, more and more of the arm is brought into play to produce the needed force.

Agogic Effects.

The striking effect of variations in speed upon a physiological movement is seen when we record a very slow "martellato" touch and the same touch made rapidly. In Fig. 134, which shows these differences, a fragment of a scale was used. At *a* the slow tempo permits the double movement characteristic of all prepared movements. The hand is transferred to the next key at a fairly rapid rate, shown by the low arced curve between the peaks. It is then lifted to prepare for the following heavy down-stroke. When the same touch is executed more rapidly as at *b*, the hand moves in the typical curve-form (similar to the low transfer in *a*), and all signs of preparation or double movement have vanished. We have found a similar difference in each other touch-form. Accordingly, the presence of preparation in extremely slow movements, and its absence in all moderately fast or rapid movements, is independent of the type of movement and must form a fundamental characteristic of physiological movement in general. The physiological and mechanical advantages of such a coördination I have already pointed out.

Furthermore, the similarity of the curve for a rapid *martellato* to the curve for all other forms of lateral arm-transfer proves that the differences among these is muscular and does not affect the manner of displacement of the hand geometrically. So long as the speed and the range of the movement are constant the hand moves in the same typical way whether we use a whole-arm motion or a hand-staccato, a firmly fixed arm, as in *martellato*, or a relaxed arm. Here we find that the type of movement of even the playing part (in this case the hand) is only indirectly affected by the muscular condition, else the curve for a *martellato* arm-movement would differ from the others. This, the records show, is not the case. Under Tone-Qualities this point is taken up in detail.

CHAPTER XIX

Arpeggio

From the standpoint of muscular movement the arpeggio, to a certain extent, may be considered an enlarged scale. The fingering is similar, and the two salient features of diatonic progression in scales : the putting-under of the thumb and the putting-over of the hand are also the salient features of arpeggio, with the difference in movement one of degree. Much that has been said about scales will therefore apply as well to the arpeggio. But range, we have seen, is one determinant of coördination and consequently, the increase of distance has its own effect, as a result of which the technique of scale-playing is not exactly a diminutive of arpeggio-playing when measured in terms of muscular coördination.

Weight.

We may take as an example of this difference the factor of weight. In the chapter on Weight-Transfer the dependence of the degree to which weight could be transferred, upon the speed of finger-lift was pointed out. In a scale the third finger lifts in order to make room for the crossing of the second finger which follows the thumb. In an arpeggio a similar condition holds, except for the fact that the distances are now greater. In a C major scale the third finger, right hand, normally plays on E, the thumb on F, the second finger on G. The distance between third and second fingers is a third, one and seven-eighth inches. In a C major arpeggio the third finger, right hand, plays G and the second finger, E above, the distance between being a sixth, or four and eleven-sixteenth inches. It is, therefore, doubly necessary that the third finger move promptly, with the result that the weight-transfer and even the legato are impaired, because one determinant of weight-transfer is the speed of finger-lift (see page 141). This is readily demonstrated by the dynamograph, on which a diatonic succession will show much less fluctuation in weight-transfer than an arpeggio played at the same speed and intensity. Needless to say, speed and loudness must be carefully controlled, because of their marked effect upon weight-transfer. Keyboard distance

thus becomes a third determinant of weight-transfer. I add it here, instead of having listed it with speed and intensity, because it is an indirect speed-variation : an increase in keyboard distance being necessarily accompanied by greater finger-speed in lift, and greater hand-speed in the lateral transfer of the arm in order to keep the rate of tonal succession constant.

The distance of a fourth, on white keys, is two and three-quarters inches. The length of a fairly long thumb, measured from the carpal joint, is about four inches. With this length as radius, it will take a central angle of about forty degrees for the tip of the thumb to stretch the interval of a fourth. This angle is normally within the range of thumb adduction and flexion. Hence a scale may be played without a shift of the arm. Even where the thumb passes under the fourth finger with the keyboard distance three and eleven-sixteenth inches, the thumb can still reach the desired key without arm-shift. But in an arpeggio the thumb covers the distance of an octave, six and seven-sixteenth inches. It is obviously impossible for any human thumb to do this unassisted. Allowing ninety degrees as the maximum angle of thumb adduction and flexion (as a matter of fact the norm is considerably less) it would require a thumb four and five-eighths inches long just to reach the outer key edge with an awkward angle of 45° at each key. A half-inch further in on the key would make the length over five inches. Again, taking the normal angle of thumb adduction and flexion of approximately fifty degrees and allowing even ten degrees more, we should require a thumb six and one-half inches long to cover the octave without the aid of arm-shift.

In any arpeggio, therefore, the passing-under of the thumb must be accompanied by some arm-shift. Since most (but by no means all) of this movement occurs in a horizontal plane, the movement in this plane may be recorded by the instrument used for similar experiments in scales. This consisted of two horizontal aluminium rods, carrying writing points which transmitted their movement to a revolving drum. By attaching one lever to the first phalanx of the thumb and other to the fore-arm at the wrist, we can accurately determine the time and space relationships in the horizontal transfer. The tracings for a slow (prepared) and a rapid arpeggio are shown in Fig. 135. For the sake of clearness in visualizing the keyboard I have kept horizontal arm and thumb movements horizontal in the figure. The time-line, given in half-seconds, is vertical, to be read upward. Displacement to the right in the figure is equivalent to movement toward the right (ascending) at the keyboard.

The striking parallelism of the lines show better than any words, the degree to which thumb action in arpeggio is accompanied by arm-shift. Whenever the thumb moves to the right, the arm moves likewise; when the thumb rests, the arm rests also. The

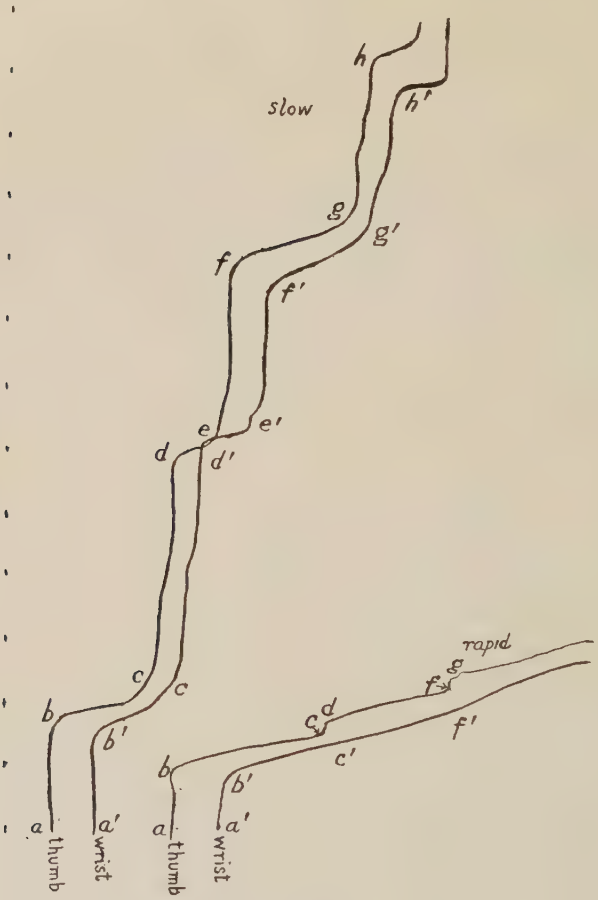


Fig. 135.

"putting-under" of the thumb, therefore, is but part of the shift, the remaining part being contributed by the movement of the arm. Without this arm-shift the angle at which the thumb-tip would play—assuming that the thumb could stretch the octave—would

make its effective use impossible. On the other hand, arm-shift alone, as later illustrations will show, is also ineffective, because it forces the thumb to leap an octave in too short a time. This means greater arm-speed, and with the inertia of the arm behind it, normally results in an undesirable accentuation of the thumb-tone.

Figure 135 is to be interpreted as follows : Slow tempo, thumb-line : *a* to *b*, thumb resting over first key ; *b–c* passing-under of the thumb to its octave ; *c–d* thumb resting on this key ; *d–e* thumb pulled slightly sidewise by passing the hand over it in order to permit the second finger to play its next key ; *f–g* thumb passing under to the next octave, same as *b–c*. *g–h* thumb resting on key. Slow tempo, wrist-line : *a′–b′* wrist stationary before beginning ; *b′–c′* fore-arm is shifted to help thumb, which is moving at the same time, to reach its key ; *c′–d′* arm stationary while second and third fingers play ; *d′–e′* arm is shifted sidewise to bring second finger over its next key ; *f′–g′* arm is shifted to help thumb, as in *b′–c′*. *g′–h′* wrist approximately stationary.

Rapid tempo, thumb-line : *a–b*, thumb stationary over its key ; *b–c*, lateral shift of thumb to reach its octave ; *c–d*, momentary rest upon this key (between one-sixteenth and one-twentieth of a second) ; *d–f*, shift of the thumb to the next octave. The section corresponding to *d–e* in the slow arpeggio is entirely absent. *f–g*, thumb momentarily at rest as at *c–d*. Rapid tempo, wrist line : *a′–b′*, arm stationary before beginning ; *b′–c′*, lateral shift accompanying thumb shift ; while thumb remains momentarily at rest (*c–d*), arm continues unbrokenly on its way with, perhaps, some very small variations in its actual speed, shown by fluctuations in its line ; *c′–f′*, path of arm corresponding to part *d–f* of the thumb movement.

Once again we find speed changing the coördination of the movement. In the slow arpeggio periods of movement alternate with periods of rest. It is necessary to mention here that the slow arpeggio was played in accordance with the principle of preparation. In the rapid arpeggio the arm-movement is continuous. It is interesting to note that the actual speed of the parts of the movement does not increase, in the slow arpeggio the actual movements are made as rapidly as in a fast arpeggio, but rest periods between, prolong the time for the entire movement. In a rapid ascending arpeggio the thumb retains periodic motion, but the lateral arm-shift is a continuous movement. It is another example of a steady, basic movement upon which are built the smaller, periodic movements of the fingers.

If the arm be transferred only in a horizontal direction, the thumb will have relatively little vertical range, since in the stretched position demanded by an arpeggio, when compared with a scale, the arch of the hand cannot be maintained so well. In order to gain thumb-range, the hand may be lifted somewhat by raising the wrist, which enables the thumb to reach its goal and play more easily. This lift at the same time carries with it a slight forward arm-motion. The shortness of the thumb when compared with the other fingers is thus aided and the thumb is brought more over the keys. This combination of movement is in line with the principle of coördination that demands greatest possible ease of motion. By combining a lift of the wrist with a forward movement of the elbow and some flexion of the thumb, the thumb-tip is brought over its key without reaching the extreme of any movement. With a quiet hand, or even minimal arm-displacement, the thumb would have to act at the extreme of its range. and the muscular strain involved would seriously impair the freedom and coördination of the movement. That is to say, the attempt to play an arpeggio with a quiet hand is opposed to both freedom and speed. An arpeggio with a really quiet hand is physiologically impossible.

We have then, in arpeggio, simultaneous movement of the wrist region in three planes: the lateral-horizontal, the forward-horizontal, and the vertical. A point on a body making such a movement will describe a path somewhat like a spiral. Before considering this as it is actually found in the records of arpeggios played, the movements in the separate planes should be discussed.

Fig. 136 is a top view of the movement of the centre of the hand in a rapid arpeggio, C major ascending and descending, the direction being shown by the arrows. This picture shows the forward and backward displacement of the hand in rapid arpeggio. In the ascending curve the hand, as the thumb plays, is drawn away from the keyboard; it is then pushed forward and raised as the thumb passes under, pulled back just a trifle as the thumb reaches for its next key and the hand passes over the thumb; pushed forward again as the thumb passes under. The descent is a simpler curve, consisting of a wide arc. This results from the forward position of the hand necessitated by the thumb-stroke. The thumb-tip can reach the keys only if the hand is well over the keys, a position which would require the second and the third fingers to play close to, if not between black keys. By shifting the arm forward and backward this restriction is eliminated. The difference between the ascending and the descending curves illustrates again

Fig. 136. Hand-movement in a rapid C major arpeggio, ascending and descending.

Fig. 137.
Same as Fig. 136.

[*To face p.* 266

Fig. 138. Hand-movement in arpeggio without passing under the thumb. Note extreme forward shift. (Compare with Figs. 136 and 137.)

Fig. 140. Hand-movement in a rapid arpeggio. Horizontal view.

[*To face p.* 267

the asymmetry of opposite movement in piano technique to which I have repeatedly drawn attention. The ascending movement is for each octave a double shift, whereas the descending movement is a single shift. The amplitudes (forward and backward distances) are likewise different. This, of course, could not be otherwise, so long as the pivot (the thumb) is at one end of the playing parts instead of in the middle.

The exact curve, however, varies somewhat with the individual. An additional curve for arpeggio made by another pianist is given in Fig. 137.

Comparison with Fig. 136 shows the individual difference. (Compare also with Fig. 129.) At the same time, however, the general fixed character of each movement, as just described, remains: the double shift for the ascending, the single shift for the descending movement, and the more forward position for the descending movement. Other differences are seen in the slant of the ascending line. In Fig. 136 the two loops of the ascending curve run parallel to the keyboard, in Fig. 137 the second loop in each octave shows a greater forward shift than the first. An extreme form of this tendency toward greater shift at the end of the octave is given in Fig. 138, which was played without any passing-under of the thumb whatever, and, as indicated, with a marked forward and backward shift of the hand. The greater forward shift is necessary because of the relative shortness of the thumb. In the usual arpeggio movement, a rise in the wrist helps to bring the hand forward, and since the photographs were made from a point above the keyboard, this rise is not shown and results in a foreshortening of the actual path traversed by the wrist. The difference in the amplitude of the forward shift, between Fig. 137 and Fig. 138, proves that in the normal playing of an arpeggio some passing-under of the thumb, as a matter of fact a marked degree thereof, is present. The hand of course can be transferred laterally without thumb-action and likewise without forward or backward shift. But the resulting arpeggio would be defective in sound and, at the same time, rather awkward in execution. In such a case the thumb would remain stationary over its key, the second and third fingers likewise. The lateral shift would then be made in exactly the same manner as that for octaves, discussed in Chapter XIII, whereupon the hand would come to rest over the keys in the next octave. This movement would be typified by that shown in Fig. 56, A, B, and analysed there as an incoördinated type of movement. Accordingly, we never find it employed in effective arpeggio. But—and this point is important—the fact that any forward or backward

shift of the hand is present, proves also that arm-movement contributes materially to the thumb-action. The mechanical space relationships analysed at the beginning of this chapter, showed the physiological impossibility of playing an arpeggio with quiet fore-arm. The photographs, with their forward and backward arm-shift, prove that such arm-movement, of course, in addition to the lateral shift, is an actual part of the arpeggio technique, present to a degree much greater than is generally supposed. It is even present quite unmistakably, in rapid scales. (See Figs. 127, 128.) All rapid exercises, therefore, requiring a quiet hand with the passing-under of the thumb do not teach the movement as it is actually used. Whatever value they have must be found in the training which they give in thumb-movement and the psychological effect which excessive movement may have on the player. There is room here for experimentation with the free arm-movement in slow practice instead of the fixed-position type of the preparation method. In fact, the relative merits of the two methods of procedure cannot be determined off-hand in any phase of technique, and the proper choice of either is of importance not only in arpeggio, but in all other passages demanding finger, hand, or arm-shift. I have always believed that the fixation or preparation method—to some extent at least—has been adhered to on the piano because of the position-technique on the stringed instruments. But analysis shows the two to be radically different. On the violin, for example, an ascending scale may be played with 2–3–4–5 (I use the piano fingering; on the violin it would be 1–2–3–4), but if further ascent on the same string be desired, the fifth finger must give way to permit the second to pass it. This can be done only with a rapid, abrupt shift. On the piano we have no such determining of position by the mechanical construction of the instrument. Even when we pass the second finger over the fifth, we add wrist-abduction, which does not help on the violin. Accordingly, the preparation procedure remains absolutely necessary for string-technique. But this does not prove its necessity for piano-technique.

Two typical arpeggio movements (again the middle of the hand) are those of Fig. 139. They are viewed from the front, that is to say, directly across the keyboard, facing the player. From right to left is the ascending curve, from left to right, the descending. The omitted portions of the curve result from the interposition of the fingers of the player's hand. We note a marked asymmetry. In the ascending curve there is considerable vertical displacement, accompanied by a corresponding rise and fall of the wrist. The

wrist drops as the thumb plays, is lifted to accommodate the passing-under of the thumb, and drops when the thumb plays again. No such vertical displacement occurs in the descending movement. Here the back of the hand traverses an almost straight horizontal line. Its level is considerably above that of the ascending curves, which in their highest points, the crests of the waves, do not touch the upper lines. The hand, therefore, is carried at a higher level, or, the wrist is noticeably raised in a descending and lowered in an ascending arpeggio. The observations all apply to the right hand. For the left hand the directions are reversed.

In Fig. 140 is shown another view of an arpeggio repeated three times. The observer here stands slightly above the keyboard level, and behind the player, to the right. Accordingly, vertical displacements which are shown in Fig. 139 in direct projection are here shown in perspective, that is to say, foreshortened some-

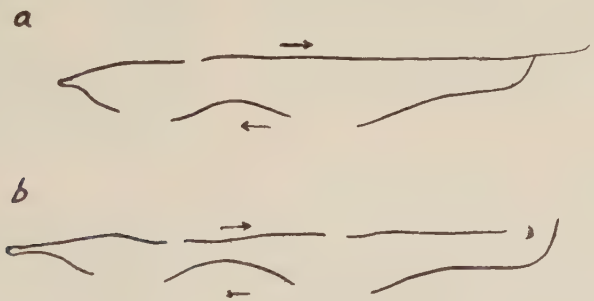


Fig. 139.

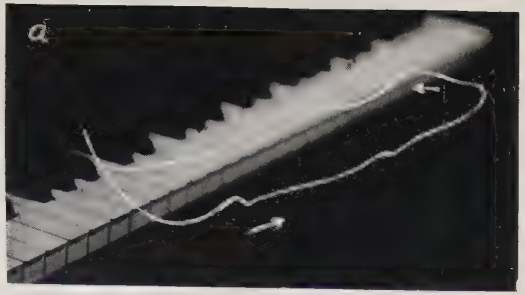
what. But the salient features of the curve are readily discernible. The ascent (from left to right) shows the vertical displacement with the lower level, and the descent, the horizontal line with raised wrist. The touching of the two lines in the middle results from the forward shift made during ascent (see Figs. 136 and 137) which, viewed from the angle at which the picture was made causes the two lines to coincide at that point. The fact should also be noted that the ascending curve shows a division into two parts similar to that characterizing the forward and backward movements (Figs. 136 and 137). Such a correlation means that the wrist, as it is lifted, also moves forward, and as it is dropped, begins to move backward. Adding to this the lateral arm-displacement results in a movement approximating an elongated spiral. In the descending movement the spiral is replaced by a forward and backward shift with a minimum of vertical movement, or, as Fig. 139

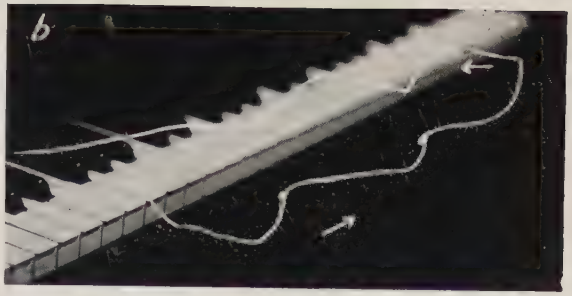
shows, none at all. The path traversed by the wrist, in a descending arpeggio therefore, is accurately represented by Fig. 136 or 137, allowing of course for the uniformly higher wrist-level at which the movement occurs. It is difficult to present to the eye in a single figure, the complete wrist-movement of an ascending arpeggio, since this occurs simultaneously in three planes. Viewed from angles of approximately forty-five degrees, so that the movement in all planes will be at least partly recorded, we get as typical curves those of Fig. 141 and Fig. 142, in which the ascending lines (left to right) show the fore-shortened spiral movement. Regardless of the angle at which the movements are photographed, the asymmetry of the descending and ascending curves is readily noticeable. It results, primarily, from the fact that the putting-under of the thumb and its subsequent playing, affects vertical arm displacement much more than the putting-over of the hand. The diagrammatic illustrations of arpeggio curves given in various text-books, showing the descent as the reverse of the ascent are not true to the physiological mechanics of the movement. I mention the point because it illustrates again the danger of drawing conclusions from mere observation of rapid movements.

Finger-Movement.

Although arm-movement, as the preceding figures show, plays a much greater rôle in arpeggio than in scales, it certainly does not entirely eliminate finger-movement. The difference between Fig. 138 in which any passing-under of the thumb has been eliminated and Fig. 136 played with normal thumb-action shows the extent to which thumb-movement modifies the curve. Then, too, some vertical finger-stroke is needed for any key-depression. Since finger-movements take place in a vertical plane and a lateral horizontal plane, photographing them from a point horizontal with the key-board and directly in front of the player will show the movement in both planes.

In Fig. 143 may be seen typical curves for the thumb (*a*) and the second-finger (*b*) movements in a rapid ascending arpeggio. (The observer is looking across the keyboard directly at the player's hand, and in the same horizontal plane. Read from right to left.) The slant of both lines shows that the lateral shift of the hand (measured by the lateral shift of the second finger), takes place simultaneously with the finger-stroke. When the tempo is sufficiently rapid no sign of preparation : transferring the thumb with quiet hand, remains. This agrees with the curves shown in Fig. 135. At the beginning of the movement (at *c*) the thumb





Figs. 141 and 142. Hand-movement in arpeggio, showing effect of intensity: *a, mp; b, ff.*

[*To face p.* 270

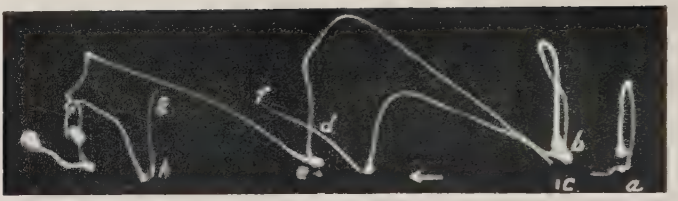


Fig. 143. Thumb and second-finger movements in a rapid ascending arpeggio. Horizontal view.

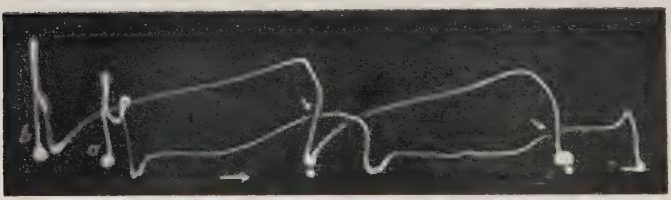


Fig. 144. Same as Fig. 143, descending. Horizontal view.

Fig 145. Hand-movement in a slow arpeggio. Vertical view. Compare with Figs. 136 and 137.

[*To face p.* 271

crossed under the second finger, hence the line made by the thumb-tip is obscured at this point. After the motion was fully under way, however, as at the middle octave, the second finger had already begun its ascent before the thumb passed under, otherwise the thumb-line could not show across the second finger line, as at *d*, where the second finger descends to play at *e*. In the record here given the thumb passed under the second finger between the points *f* and *g* the rather wide distance resulting from the fact that the second finger was at the same time moving in the same direction as the thumb, hence lengthened the distance of obscurity. Such a coördination indicates the non-legato character of a rapid arpeggio, which, as a touch demanding finger-repetition (especially thumb repetition) naturally precludes a high degree of legato (see p. 141). The records of arm-movements in the various planes bear this out, since such arm-movements tend to pull the fingers from the keys, either vertically or horizontally and hence destroy the legato somewhat.

This simultaneity of movement holds for the descending arpeggio as well, a typical movement form of which is given in Fig. 144, *a* being the thumb-line, *b* the second-finger line. As in the preceding figure the observer is looking across the keyboard at the player's hand. (Read this figure from left to right.) The thumb passes behind the second finger at the points marked with arrows. If the preparation-theory held, the thumb would have to be over its key before the second finger played. The fact that, in actual rapid playing, the thumb passes the second finger while the latter is already descending, points out not a sequence of movements (first thumb, then finger), but simultaneous movement.

But if the arpeggio is non-legato, the weight of the arm cannot be transferred from finger to finger, much less from finger to thumb. So that, here again, we cannot speak of weight-transfer or weight-touch.

Tempo.

In the chapter on Scales, tempo was named as one determinant of the movement. A similar effect is noticed in arpeggio. The forms which we have thus far been considering are all records of the rapid arpeggio, as it is found in many etudes and advanced compositions. When the tempo is reduced, the mechanical basis of the movement changes. The same arm-weight is to be moved through the same distance, but at a different rate of speed. The distribution of forces must, therefore, vary. In the first place, the degree of legato may be increased because no need for a rapid

finger-lift exists in a very slow arpeggio, and upon slowness of finger-lift legato or weight-transfer depends. In the second place, the need for holding each key until its successor is played will cause a change in the arm-movement.

The slow movement may be made in either of two ways: by a continuous steady movement of slow rate, or by a more rapid shift from one position to another, with momentary rests at these positions. In the case of slow scales (see Figs. 127*a*, 128*a*) and slow lateral arm-transfer (see Fig. 135) the movement consisted not of a uniform, slow movement, but of a more rapid shift into the new position followed by a short rest in this position. The same thing happens in a slow arpeggio of which Fig. 145 is a typical example. The sharper line shows the ascending curve, the duller line the descending curve. The mid-point of the hand was photographed. A study of the figure shows agreement with the physiological mechanics of the movements studied in earlier chapters. The presence of light spots, with fainter lines between, shows the points at which the hand was relatively at rest. The steady "swing" of the rapid arpeggio has thus been replaced by a series of lateral shifts and rests. The displacement of similar letters, particularly the C's, which are a key and a half nearer the bass in the descending than in the ascending curve, illustrates the pronation of the forearm (hence the hand also) which is greater in a descending than in an ascending arpeggio. The pronation naturally throws the point of light towards the thumb-side of the hand. Some movement in the radio-ulnar articulation has thus taken place. The forward and backward shifts, noticeable on both the ascending and the descending curves, result not only from a forward and backward arm-shift, but also from a raising and lowering of the wrist: raising throws the hand forward, lowering does the reverse. This forward shift is most noticeable in the descending C's, and results from the shortness of the thumb and the raising of the wrist made to facilitate the legato with the following G. The several smaller shifts from C to E and from E to G of the ascending curve show a modified *portamento*, or rather arm-legato, with moderate raising and lowering of the wrist.

The player, in this instance, was left free to play the keys as he would under actual playing conditions. The results show that, when this is done, a slow arpeggio subdivides itself into a series of separate movements. The entire arm takes part in the movement, and there is no attempt to restrict movement to a lateral straight-line arm-shift. The touch-form closely approaches the arm-legato which we have already studied.

The standard form of preparatory exercises for arpeggio demands a quiet hand, or at any rate, no forward or backward shift. (It is a practice-form similar to that given for scales.) And, for the same reason as in scales, it drills a movement that is not used in actual playing, not even in slow arpeggios. Its value, therefore, must lie in the emphasis which it places upon a particular phase of the movement : the actual passing-under of the thumb. Such exercises form an extreme type of movement, of which the type shown in Fig. 138 forms the opposite extreme. Neither type is used in actual playing to the exclusion of the other type. Instead, both phases are always present. There is some passing-under of the thumb, and there is some hand-shift or arm-shift before this passing-under is complete. It is another instance of a basic arm-movement, upon which, while it is in progress, the more distal and smaller finger movements are superimposed.

The slant of the curves for both finger and thumb in the rapid arpeggio approximates that for the slow or moderately fast lateral arm-transfer more closely than that for the rapid arm-transfer, inasmuch as the curves are somewhat angular, with their apices nearly over the second of the two keys played. (Compare Fig. 144 with Fig. 66, *b* and *c*.) There is no discrepancy here. In spite of the speed of the arpeggio no single finger-movement involves rapid repetition. Between each two thumb-strokes, two finger-strokes intervene, and between each two second finger-strokes, a thumb-stroke and a third finger-stroke intervene.

Finally, the asymmetry of the curves for slow arpeggio should be mentioned. In neither case is descent the geometric or physiologic reverse of ascent. This has already been mentioned for the rapid arpeggio, and Fig. 145 shows that it holds as well for the slow arpeggio, the sharper line (ascent) having a contour quite different from the paler line (descent).

Intensity.

Since amplitude is a determinant of intensity in all physiological movements, we can expect an increase in the amplitude of the arpeggio movement with an increase in tone wherever the movement is in line with tone-production. The difference is shown in Fig. 139, for the vertical plane, *a* being an arpeggio played *ff*, *b* one played *mp*. The greater vertical distance between the two lines in *a* indicates the increase in amplitude. However, the actual vertical displacements along the ascending curve in *a* are, in this record, not greater than in *b*. This results from the fact that in order to produce greater tone the wrist cannot be as relaxed as in soft tone-production.

(See Relaxation.) And with less relaxation comes less vertical wrist-movement. The difference is so slight here that I do not care to risk a definite conclusion on this point. But all doubt about the effect of intensity upon amplitude of movement is dispelled when we study Figs. 141 and 142. Here are four keyboard views, *a* in both figures representing *pianissimo* arpeggios, *b* representing them *fortissimo*, all played *allegro*. The increase in amplitude shows in both the vertical and the forward horizontal planes. Needless to say the left-hand ends of the curves, recording the approach to and departure from the keyboard, are not to be used for interpretation. Such an increase in arm-movement is in accordance with the principle of spread of tension. Not that the arm-weight is used. This is just as impossible, where thumb-transposition is

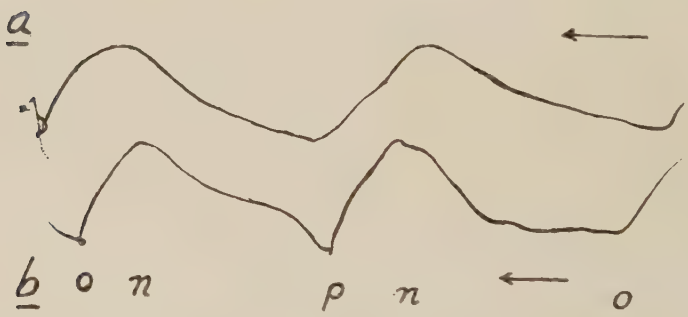


Fig. 146.

involved, in *fortissimo* as in *pianissimo*. As a matter of fact it is less possible in loud than in soft passages. The spread of tension and the greater arm-movement result from the necessary fixation of fulcra, by means of which the fingers can transmit the force of their stroke into the key without loss. This, in turn, means that with an increase in tonal intensity goes an increase in range or speed of finger-movement. To verify this, the movement of the third finger was recorded for a *pianissimo* and a *forte* arpeggio, Fig. 146. The point of light was attached to the second phalanx and the movement photographed directly across the keyboard. Differences in the height of finger-lift are smaller than might be expected. This results from the fact that in any rapid arpeggio the third finger must be lifted in order to pass readily over the playing thumb,

and the finger-lift in a soft arpeggio is thus greater than that actually needed for tone-production with that finger. Some difference remains, however, *a*, the curve for the soft arpeggio being about four-fifths as high as that for the loud arpeggio, *b*. The major difference, however, is in finger-speed, the descent of the finger in *b* being more rapid (more nearly vertical) than the similar descent in *a*. The type of curve for both *b* and *a* is interesting also in that it shows that the maximum point of finger-lift is reached immediately before key-stroke, and not immediately after key-release. In other words, the finger either is not lifted rapidly to its maximum height and held there until the next descent begins, but is lifted gradually, reaching its maximum lift just in time for the next descent, or the lateral shift of the hand is more rapid in places. This causes the points *n* to be shifted toward finger-descent. During finger-lift the hand shifts over the thumb thus displacing, laterally, the third finger. This shift does not account for the entire asymmetry, however, since shortly before *n* is reached both *a* and *b* show an additional finger-lift where the curves rise more abruptly. (Fig. 135 showing the lateral shift of the hand proves the steadiness of movement in a rapid arpeggio.) The shift is more noticeable in *b*, for the loud tone, and illustrates the preliminary thrust (*Anhub*) described in detail under Finger-Stroke.

The practical significance of this effect of intensity upon finger-stroke in arpeggio is in the fact that strength of finger muscles again is shown to be necessary, this time for a loud and clear arpeggio. Since it is impossible to transfer arm-weight in a finger sequence such as that demanded by arpeggio (see Chapter XI), only finger-strength can supply the force, if the tones of the arpeggio are to be evenly loud. Arpeggios played with this attempted arm-weight transfer are not clear, the third or fourth finger especially playing weakly. The same condition exists on a smaller plan in scale playing. In fact, it is doubly necessary to develop finger strength in arpeggio because the fingers play in an abducted (spread) position ; and flexion, in this position, is more difficult than in the normal scale-position. Fig. 146 shows the typical finger thrust for a loud tone, proving that it is finger-stroke that is responsible for the tonal increase. If it were arm-weight, no additional finger-lift would be needed ; in fact, the best transfer can be made with least finger-lift, because lack of percussiveness (see p. 144) has been shown to be one determinant of weight-transfer. *b* in Fig. 146 would, in such a case, show less amplitude and steepness than *a*, which is just the opposite of the actual condition.

Arpeggio technique, therefore, demands more than arm-shift, the passing-under of the thumb, and the passing-over of the hand. It demands the training of the fingers for a firm stroke in chord position. The various broken-chord figures, within a single octave, played forte, with the tones held, thus form an excellent preparatory group for arpeggio, to which the thumb-shift and hand-shift may be added as the next steps.

CHAPTER XX

Miscellaneous Movements

The graphic recording of pianistic movements opens a field of tremendously interesting possibilities. Not only does it throw light upon the hitherto obscure question of individual style, as I shall attempt to show in a later chapter, but it also simplifies problems of fingering, aids the teacher in diagnosis of movements, the details of which are too quick for the eye to detect, reveals the limitations of free movements caused by the mechanical construction of the keyboard, and illustrates the geometric deficiencies of awkward technical movement, among which the movements of untalented pupils are prominent. Then, too, there is the mere theoretical interest in the form and proportions of the geometric figures themselves.

The field is wide—all too wide for an adequate inclusion in a single volume, because the entire literature of the piano stands at the disposal of the investigator. The selection from this literature of representative examples is not an easy one ; and generalizations from insufficient examples are fraught with danger. I have selected for presentation a number of photographs of certain typical pianistic movements : chromatic octaves, octave chord figures, broken chords, diatonic figuration and the like, and have then added a few miscellaneous examples taken from well-known passages of some standard compositions. In reading the curves the following relationships must be remembered :—

Since the middle of the hand was the point photographed, its projection (in octave figures for example) will not correspond to the lettered keys of the keyboard. When an octave C is played, the mid-point of the hand is normally over F or G, sometimes shifted more one way or the other, and its projection will be so recorded.

All passages descending on the keyboard are recorded by curves which must be read from right to left. The curves for all ascending passages must be read from left to right in the figures. The observer stands directly over the keyboard looking vertically down at the player's hand. Records are of the right hand, unless otherwise stated.

The beginning of the curves, where the hand approaches the first key played, and the end of the curves, where the hand either remains on the last key, or is withdrawn from the keyboard, are of no consequence in the present study.

Fingering.

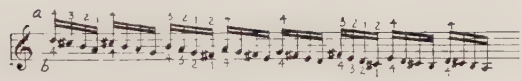
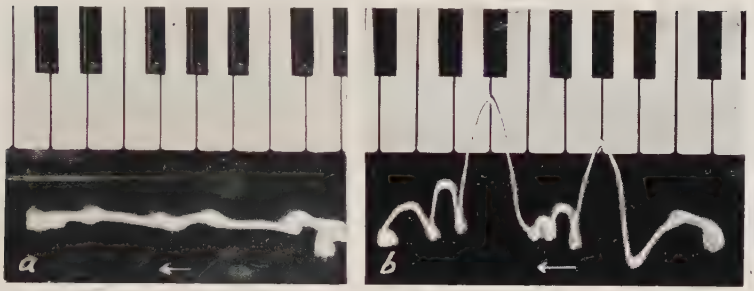
The value of one type of fingering over another rests, or should rest, in the greater ease and smoothness of the requisite movement in so far as it can meet the musical demands of the passage. The wide variation found in the fingering recommended by editors such as D'Albert, Von Bülow, Joseffy, Klindworth, and Busoni, is of more than mere academic interest. It reflects, very distinctly, the individuality of technical style of the various editors. A change of a single finger may mean a considerable change in the movement itself. Fig. 147 illustrates the difference between the playing of the given passage when the fingerings given are used. The fingering above the notes refers to curve *a* ; that below the notes, to curve *b*. The straight line effect in *a* is typical of the older school, in which hand- and arm-movements were reduced to a minimum ; *b*, in the same figure, typifies the later free-arm movement, made necessary by the placing of the thumb on black keys. The analysis in preceding chapters throws some light upon the differences in value between two such fingerings. From a muscular standpoint that at *a* is to be preferred, since it produces the desired tonal effect with a minimum of movement. The forward and backward shift of the hand in *b* adds nothing to the tonal result, and must, therefore, from a purely muscular standpoint, be considered superfluous movement. The advantage of *b* lies in the slightly greater simplicity of fingering, 4-3-2-1 being uniformly repeated. But this advantage is outweighed by the loss in accuracy of dynamic control which normally accompanies a shift of the hand. The inequality can, of course, be overcome with practice, but often some vestige of it remains. A movement, the object of which is equal stroke-intensity, is normally more difficult to execute if various parts of the hand and arm are used than if the same part or similar parts are used. The forward and backward shift in *b* Fig. 147 is an arm-movement, occurring only when the thumb plays a black key. But it covers also the time during which the other fingers are playing. It adds, therefore, a difficulty in finger control. And a sufficiently sensitive dynamograph will record such variations even after prolonged, and apparently successful practice. In such a case the differences are reduced to a minimum which is too small to be detected at the rate or at the dynamic level at which the passage is played. But



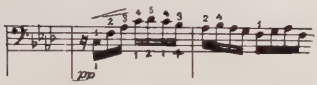
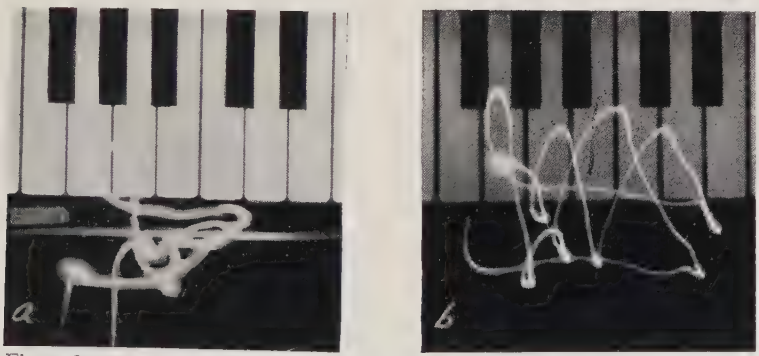
Fig. 147.



Fig. 148

Figs. 147 and 148. Effects of fingering upon hand-movements.

[*To face p.* 278

the fact that their minuteness prevents their being immediately recognized as intensity differences, does not mean that they may be ignored, because in these and similar minute differences may lie one factor of individual style. The trill in thirds at the beginning of Chopin's Etude, Op. 25, No. 6, may be played with a slight forward and backward shift of the arm. But it will normally sound less " finished " than if done purely with finger-action. And as a matter of fact it is often played with a quiet hand by the finest technicians.

From the standpoint of physiological mechanics, then, a passage should be fingered so that tones of equal intensity are played by similar parts of the arm ; in the example given, as at *a*. On the other hand, where dynamic variations are wanted, a change of the playing-unit is often very desirable. If, for example, the F-sharp and the C-sharp in Fig. 147 needed an accent, the use of the thumb could give it more readily and physiologically more economically than the fingering at *a*.

An interesting example of the effect of fingering upon the movement is given in two measures from the last movement of Beethoven's Sonata Appassionata. The fingering above the notes produces the curve shown in Fig. 148*a* ; the fingering below the notes, that in Fig. 148*b*. The two curves, with the exception of the loop at the inner left hand side, are entirely different ; one shows numerous pronounced forward and backward arm-shifts, the other, a relatively quiet hand, the arm shifting only when the passage passes from F-minor to its later repetition a half-tone higher. The lateral shift of the hand is likewise less in *a* than in *b*, covering approximately four keys in one case and six in another. The quiet hand is normally to be preferred. However, other things frequently affect this difference. The fingering at *a* is rather difficult for small hands, or short fingers, whereas that at *b* for the same type of hand is considerably easier. As a matter of fact the record at *b* was made by a pianist with a small hand, who insisted that the fingering was decidedly superior to that at *a*. I suspect that this rating resulted from his own playing of the passage. And if such a preference exists for this passage, similar preferences will exist for other, similar passages. The shift of the arm is substituted for abduction of the thumb, and arm-movement is used to make up for the lack of stretch between fingers. The playing, therefore, takes on certain fairly uniform characteristics which would be absent in the playing of other pianists. Thus we approach the technical style of the player. The example given is another illustration of the effect of physiological differences upon instrumental style. The converse of this

relationship is found in the adaptation of fingering to the hand-formation of the pupil. The fingering of a passage should not, in many instances, be applied fixedly to all hand-types. Instead, it should be varied to suit the structure of the individual hand, so long as the change is in keeping with the musical context of the passage. A particular abnormality, let us say, high webs between the third and the fourth, and between the fourth and the fifth fingers, will make abduction among these fingers quite difficult, and the player frequently substitutes the third for the fourth finger in chordal structures demanding wide abduction.

Keyboard Limitations.

It is a well-known fact among pianists that the standard build of the piano keyboard is not the most perfect form. As a result, numerous other types of keyboard have been invented from time to time, such as the curved type, the duplex type, the Janko-keyboard, and others. In spite of the advantages offered by these, the straight horizontal form, dating back to the precursors of the piano, has maintained its preëminent position. Piano technique has been forced to adapt itself to this form of keyboard, and the effect of the latter upon technical movement may be strikingly shown by the limitation which the fall-board imposes upon the forward arm-shift. The question affects our analysis inasmuch as it may lead to wrong inferences from the study of the lines of movement. In many instances the particular form of movement used is not the best or most free—that is to say it is not the best coördinated movement possible, but is in part definitely determined by some extraneous factor, some mechanical point of construction, such as the position of the fall-board. This is the vertical board immediately behind the keyboard. It is folded back into its vertical position when the piano is in use, and is pulled forward over the keyboard when the instrument is not in use. The forward movement of the hand or arm is, therefore, limited definitely; whereas the backward movement, away from the keyboard toward the body of the player, is relatively unlimited.

The following ascending passage, played in octaves, C–E-flat–G-flat–A–C–E-flat–G-flat–A is one in which both forward and backward and lateral shifts are symmetrical with regard to the keyboard. E-flat is approached from C, as A is approached from G-flat; the key-relationship C–E-flat–G-flat–A is symmetrical to that of G-flat–A–C–E-flat. The movement of the hand, however, in playing this passage rapidly, is not entirely symmetrical. In the figure here given, Fig. 149, the passage was played in octaves

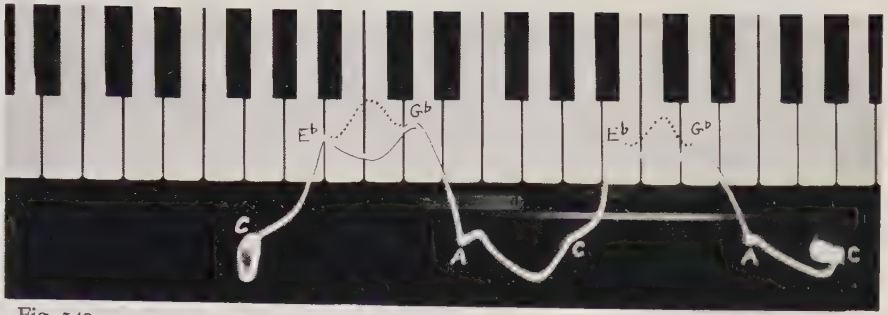


Fig. 149

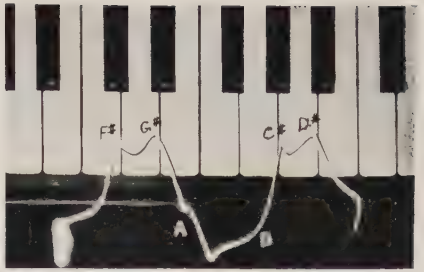


Fig. 150

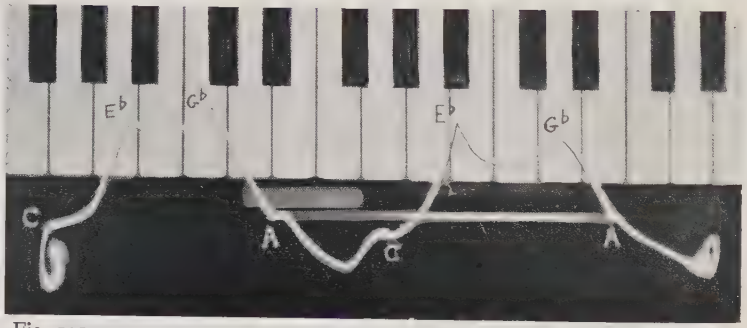


Fig. 151

Fig. 149, Fig. 150, and Fig. 151. Effect of fallboard upon forward arm-shift, showing inhibition of forward movement.

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The Fallboard of a conservatory piano after two years' use. The scratches show the countless impacts of finger-tips and fallboard, resulting in interference with free movement. The lower picture is an enlarged photograph of the section marked above.

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ascendingly, *allegro*, and at moderate intensity. The curve illustrates the movement of the centre of the hand. As the hand passes from C through E-flat to G-flat, its forward motion is muscularly inhibited so as to avoid contact of the non-used fingers with the fall-board. But when the hand passes from A to C, there is no need of this inhibition, hence the hand continues in the general direction away from the keyboard and turns about midway between A and C. This loop is clearly shown between the letters in the figure. If it were not for the fall-board, the curve would take a form approximately like that indicated by the dotted lines. That is in keeping with the principle of physiological movement deduced in the chapter on Lateral Arm-Movement ; that a change in direction is made gradually whenever possible, avoiding angles and substituting curves.

This limitation or flattening of the curve is not the result of the particular technical passage used. It exists in all movements involving a forward shift of the hand. Instances will be found in Fig. 150 which records the movement of an ascending E-major scale, played *allegro*, in octaves, with first and fifth fingers throughout ; also in Figs. 158, 161, 211, 212, 213, and 217. Figs. 211 and 212 show the left hand octave passage in Chopin's A-flat Polonaise ; and Fig. 158 shows flatness of the inner half of the ellipses illustrating the opening measures, right hand, of Chopin's Etude in F Major, Op. 25, No. 3. It shows also in all elliptical motions involving black keys (such as that in the Chopin Harp Etude, Op. 25, No. 1) where it results in a flatness of the ellipse on the side near the fall-board. In the scale passage, Fig. 150, if played freely, the curve between F-sharp and G-sharp should be an approximate symmetrical curve to that between A and B in the same figure. In all the figures just mentioned the line of movement is that of the middle of the hand. The piano manufacturers could readily remove this limitation by dropping back the fall-board a few inches, a change which would not interfere seriously with any other point of construction, but which would make the playing of octaves or mixed figures on black keys considerably less constrained. A glance at the fall-board of any used piano will show innumerable arcs and scratches where the finger-nails of the player have come into unavoidable contact with the board. See Plate XXVII. This in itself is sufficient cause for dropping back the fall-board. Thus the asymmetry of physiological movements in opposite directions, which I have pointed out for lateral horizontal movements, exists in a modified form for the forward and backward movements also. The change from a forward to a backward arm-shift is made differently

from the reverse change. The angular aspect of the inner corners (near the fall-board) demands a muscular coördination of greater strength and brevity than the more curvilinear outer portion of the figures. There is greater inhibition in the checking of a forward movement, and a great amount of inhibition is normally opposed to a well-coördinated movement, the intensity of which does not demand the excessive inhibition. By removing the fall-board, or placing it a few inches back, the arm could move in a more curvilinear form. I pass the suggestion on to the manufacturers.

Intensity Effects.

In earlier discussions of various movements, especially the lateral arm-shift, the effect of intensity showed in variations in vertical displacement. I add a figure to show that it does not noticeably influence the movement in the horizontal plane. Fig. 151 gives the curve for C, E-flat, G-flat, A, C, E-flat, G-flat, A, the same as that in Fig. 149, but played, this time, *ff*. The curves of the two figures are essentially alike ; with a possible intensity effect reflected in the slightly sharper corners of the second figure, corresponding to the percussion of the black keys E-flat and G-flat. This is a natural correlation, since with the increased speed necessary, the force of the moving body increases and greater muscular fixation is needed to change the direction. The spread of fixation is shown in the sharper corners.

Coördination and Incoördination.

In movements requiring a shift of the hand before the original figure is repeated, the shift is accompanied by an added coördination that affects the fingering or the playing of the subsequent figure. From a mechanical standpoint it would be advisable to have hand and fingers in the same position for each repetition of a figure. An example of such repetition is found in the treble passage, right-hand, from Liszt's Lorelei, illustrated in Fig. 152. The passage is frequently played by pupils—probably on account of slow practice—by passing over the fourth finger in a legato manner, the distance being covered by turning out the elbow also. As a result the hand and fore-arm, as G is played, are in a poor position for playing the figure at its lower pitch. A quick jerking-in of the elbow is necessary to bring the thumb over the next key (A-sharp) that it plays. But angularity of movement is normally opposed to coördination, and, as a matter of fact, the tonal production suffers somewhat when the passage is played as here described. The defect is clearly shown if we record the course of movement

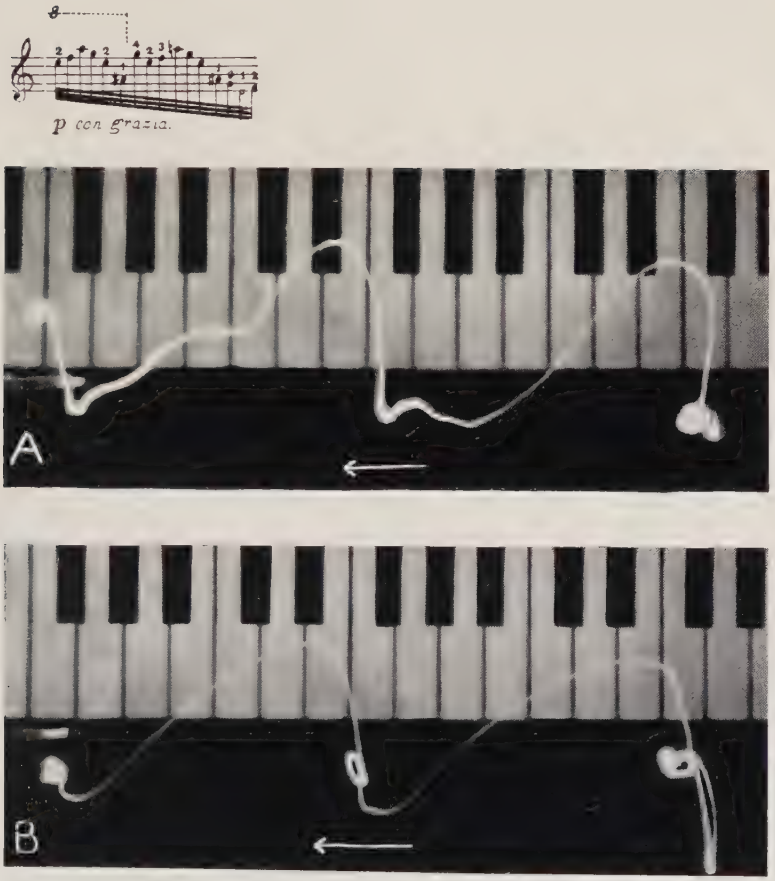

Fig. 152. Effect of fingering and arm-shift upon the smoothness of a technical movement.

[To face p. 282

of the centre of the hand, as in Fig. 152, where the curve for the first presentation of the passage, at A, is more irregular and points to an incoördinated movement ; that at B (the same keys as in the first part) is the typical, smooth, free curve.

Suppose now, that the movement is made by a rapid shift of the arm without abduction at the wrist. A fingered-legato between A-sharp, first finger, and G, fourth finger, will then, of course, be impossible. But, apart from the fact that the pedal may be used to secure the legato, the speed at which the passage is played makes the non-legato leap from A-sharp, thumb, to G, fourth finger, not too noticeable. At the same time, the hand is at once in the same position to play the second part of the figure as it was to play the first part. Accordingly, we may expect a better curve than before, since the movement is less angular. In Fig. 152 B the irregularities of Fig. 152 A are absent and the second part of the curve (left side) becomes muscularly as well as tonally a repetition of the first. When the problem is not complicated by questions of accent or duration, this type of curve is to be preferred to that of Fig. 152 A, in which similar tonal figures are played by dissimilar movements.

An additional difference may be seen in the forward projections of the two curves over the keyboard. In Fig. 152 A, the hand is closer to the fall-board (farther over the keys) than in Fig. 152 B. Whereas, in the free movement the hand plays its thumb on its inward path, in the incoördinated movement more angularity is present, shown at the irregular bright section joining the two curves. The same section forms a small graceful loop in the coördinated movement.

This is a concrete example in which the slow type of practice shown will never lead to a proper execution. Instead, the legato character should be somewhat sacrificed in the slow practice and the hand transferred as in Fig. 152 B, instead of changing the arm-movement to retain the legato. It illustrates, once again, the effect of speed upon muscular coördination and the impossibility of transferring a movement learned slowly to the same passage played rapidly, without muscular readjustment.

We may write, as a general principle : the repetition of a figure, should, so far as possible, be accompanied by a repetition in the position of the hand and arm and in the muscular coördination. So far as the application of this principle to figures such as that of Fig. 152 is concerned, it is better to sacrifice the finger-legato at the point of arm-shift than to introduce a lateral twist (abduction) at the wrist. This covers the entire field of arpeggiated passages

of sufficient extent to include arm-shift, and illustrates again the fact that rapid arpeggios are necessarily played non-legato.

If these observations are correct, the records obtained from technically untalented pupils should show marked variations in the geometric aspects of the movements from those of talented pianists, both as to form and as to angularity. The records which follow are those of an adult beginner, after one year of intensive training. It is a case of undoubted subnormal muscular coördination, which no amount of training will materially improve. Fig. 153*a* illustrates the right-hand movement in a slow descending C major arpeggio. The curve does not fit either the slow or rapid type at all. The slow type of discontinuous movement would record bright spots connected by faint lines, as in Fig. 145: the typical "preparation" curve. Furthermore, all curves of well-coördinated movements are relatively free from angles, unless the direction is changed at the moment of key-impact, which is not the case here. That the movement of Fig. 153*a* was fairly continuous is shown by the relative absence of noticeable bright spots. Yet, in spite of this continuity, the line is irregular, the second octave varying from the first and the variations within each octave being likewise irregular. The line shown in the figure is the typical result of a highly-incoördinated, awkward movement. Since the movement was made very slowly, speed cannot have been a determinant of the curve.

If speed is insisted upon, in the case of subnormal coördination, it results in a loss of accuracy, both as to keys struck and dynamics. Fig. 153*b* is the hand-curve for a rapid, ascending C major arpeggio, in which less than half the proper keys were struck, the third octave being an undecipherable jumble of sounds. This part is shown in the irregular ending at the right side of the figure. For the first two octaves there is a recurrence of curve, but by comparing this with the well-coördinated ascending arpeggio curves, shown in Figs. 136 and 137, a marked and important difference comes to light. In Fig. 153*b* the hand was transferred as a unit without any thumb-action whatever, with the wrist held noticeably in, as opposed to the "out" position of the coördinated movement. Of the two, the former demands a somewhat easier finger-movement, especially thumb-movement. It is a less complex movement, hence is natural to the incoördinated response. In agreement with the principle of fixation stated in the chapter on Coördination and Incoördination, the wrist is held in and is neither flexed nor abducted during the movement. The differences between the coördinated and this incoördinated arpeggio movement are thus

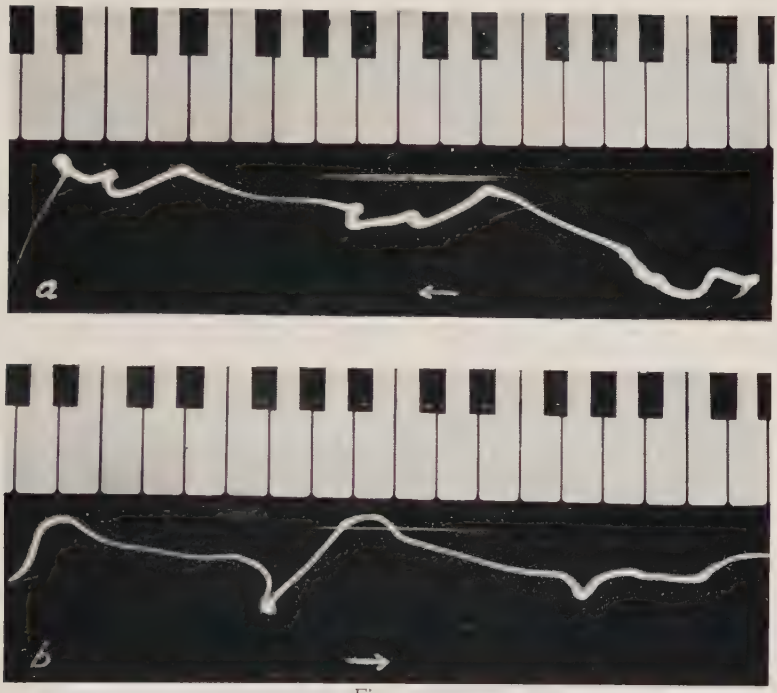

Fig. 153

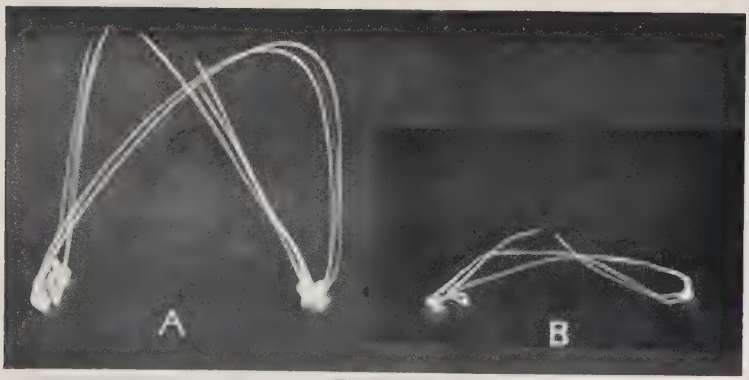

Fig. 154

Fig. 153 and Fig. 154. Incoördinated movements. Note irregularities of curves.

[*To face p.* 284

seen to be differences in the degree of activity of the finer muscles of hand and fingers. Through two octaves at least, the curve shows a normal freedom and continuity, being, with one exception and that a necessary one, free from irregular angularity. The fact that the curve itself does not fit the arpeggio does not alter the fact that the larger arm-movement was normally made. Had the finer finger- and wrist-movements been properly superimposed upon this arm-movement, the arpeggio would have been satisfactory. As a matter of fact, in the particular case here recorded the chief difficulty had always been in coördinated finger-movements, and a careful analysis of the case has brought to light a marked subnormality of the finer adjustments of the kinesthetic sense, both as to adaptation and retention. Other records made bear out these observations. The awkwardness of an incoördinated piano movement is usually not in the fundamental arm-movements, but in the finer or smaller finger- and hand-movements which must accompany the arm-movement in all complex figures. Separate these components, and much of the awkwardness vanishes. That is to say, the fact that the pupil may execute successively each part of a complex movement correctly or smoothly, is not proof that he can do so simultaneously. And the converse of this, the view generally held by leading pedagogues: that the question is primarily one of coördination, a psychological problem, is, partly at least, substantiated by experimental evidence such as that given in the preceding paragraphs. This in no way eliminates the purely physiological variations. The latter, when present, affect even the fundamental movements and hence must also affect the complex movements.

In our study of relaxation and of coördination the presence of relaxation periods immediately after tone-production was pointed out. The curve for very slow lateral arm-shift, for example, showed a horizontal transfer to the next playing-position, then a rest at that point (the equivalent of relaxation) and finally the lift and drop necessary for tone-production. This typical curve is shown in Fig. 154. A lateral arm-shift of one octave made by a pupil with subnormal technique, at a slow tempo and at an intensity approximately *ff*, is recorded in Fig. 154 A, and a similar movement, very slow, but this time *mp*, is seen in Fig. 154 B. The typical loop-form of the rapid curve analysed in Chapter XIII is retained, whereas in the coördinated movement the slow transfer takes the form of Fig. 66, *a*, *b*, *c*. That means that the relaxation periods between tone-production are absent. Instead, the entire arm is slowly transferred to its new position at a relatively uniform

speed. The mechanical waste of this procedure is given in detail on page 104 in connexion with the explanation of the initial maximal muscular contraction. That holds for both extremes of intensity. Even in the production of a soft tone (Fig. 154 B) the arm is transferred in this constrained manner.

On the other hand, the effect of intensity is the same in these records as in those of coördinated movements ; an increase in tonal intensity is accompanied by an increase in the amplitude of the movement, the difference in the heights of the two curves we are considering leaving no doubt as to this correlation. The subject making these records had not practised the movement to any extent. As a matter of fact, the first strokes showed the difference in amplitude. Accordingly, it seems that gross control of tonal intensity is a natural muscular coördination in the adult. It does not have to be acquired through prolonged practice. The question has its ramifications into the field of pedagogy since it helps to establish the time at which problems of intensity and the correlated problems of tonal balance should be introduced into the training of the child. If, as the records here show, an increase in amplitude accompanies an increase in tone without preliminary training, as a natural muscular reaction, this difference in amplitude may be utilized quite early in the training of the child to secure the dynamic effects of melody and accompaniment. As a matter of fact, many teachers use precisely this method. The hand playing the accompaniment is lifted as little as possible, while the lift of that playing the melody is purposely exaggerated, either into an arm portamento or into an arm-legato. All the records I took of this phase, as well as observations of pupils, support the theory that amplitude of movement and tonal intensity are a basic correlation, present in early childhood.

And consequently, questions of tonal balance are best approached in compositions permitting the exaggerated differences in amplitude to which I have just referred. The portamento and the arm-legato thus gain in value as the early touch-forms in the training of the child. The same condition holds for dynamic differences among the smaller movements of the fingers, made necessary as the child advances. Here, too, the approach is easiest by exaggerating the finger-lift in the accented finger, and minimizing it in the unaccented finger. For, if we are dealing with a fundamental form of muscular and sensorial reaction, this will hold for the movements of fingers and of hand as well as for movements of the arm.

An additional record of incoördinated chromatic octaves, right

Fig. 155

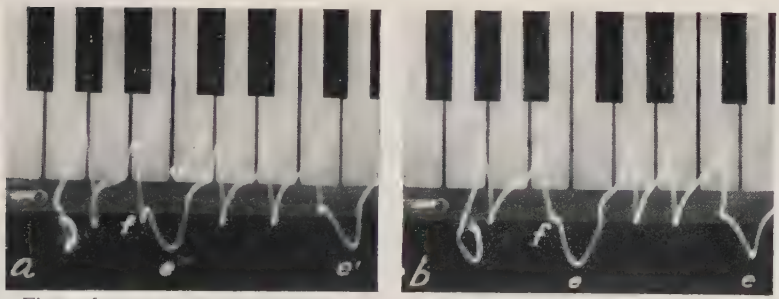

Fig. 156

Chromatic octaves, *allegro moderato ;* Fig. 155, incoördinated, Fig. 156, coördinated.

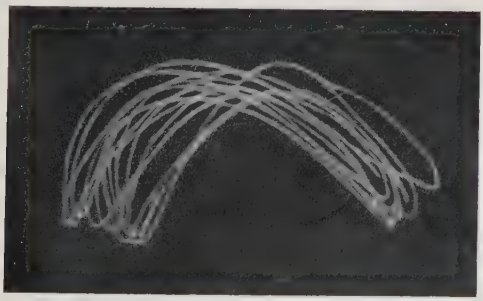

Fig. 157. Lateral arm-shift, octave, incoördinated.

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hand, ascending through one octave, fairly rapidly, is given in Fig. 155. Comparison with the records of similar, but coördinated movements, Fig. 156, shows the incoördinated movement to contain the greater number of convex arcs, which originate at the player's shoulder. Beneath the curve I have dotted in diagramatically, the approximate path which the hand describes when the movement is made without the aid of wrist-abduction, with forward and backward movement of the upper arm accompanied by slight extension of the elbow. The two curves are very similar. In the actual record a very small amount of wrist abduction is noticeable at the beginning of each forward-stroke where the curve is slightly looped or bent. But compared to that shown in Fig. 156 the amount is negligible. Here, as in the curves given for the arpeggio and the lateral arm-transfer, we find movement primarily restricted to the larger joints. The building up of smaller hand and finger movements on these larger movements is conspicuously absent. The forward and backward arm-movement is excessive. (Compare with Fig. 156.) The subject making the record of Fig. 155 has both short fingers and a short thumb. As a result, the projection of the hand is farther over the keyboard than that of a normal adult hand (Fig. 156). Such differences as these point out, quite clearly, the effect of physiological structure upon pianistic movement, and emphasize the need for adapting the particular movement to the particular hand.

Fig. 156 *a*, *b*, shows the hand-movement, right hand, top view, in chromatic octaves played non-staccato and allegro, *a* with thumb and fifth finger used for all keys, *b* with the fourth finger on black keys. The effect of this change of fingering on the forward or backward hand and arm-movement is scarcely noticeable; it shows itself in the slightly smoother line of forward movement. The curves show again the typical muscular asymmetry of mechanically symmetrical movements; in each case the forward motion of the hand is diverted more or less abruptly near the middle of the stroke, whereas the return stroke is a straight line. Mechanically the keyboard demands the same line for both movements. The asymmetry here is explained by the fact that the player, after passing from a white to a black key, lifts the wrist (action and reaction) and thus moves the centre of the hand slightly forward; whereas the passage from a black to a white key is more in the nature of a glide, in which there is no additional wrist flexion or extension. The depression of the black key does not begin at the apex of the forward movement, the point marked *C*, but at *d*, the passage from *d* to *c* resulting from an ascending wrist and

some inertia. The loops at *e* and *e'* show the typical inertia projection: the tendency of the movement to continue in a straight line, beyond the points where the keys are struck, *f*. If two black keys were played in succession, we should get no such loop, because the fall-board of the piano would prevent it. (See Fig. 150, representing the E major scale.)

When speed is demanded from an untalented pupil, either or both of two things may take place: the gross movement, or the aim, is incorrect, or both are incorrect. In the arpeggio already studied, both aim and movement were wrong, the fundamental movement, however, being much more finely coördinated than the movements of hand and fingers. This belief is borne out by the record of a rapid lateral arm-shift in which separate hand- and finger-movements are absent. Fig. 157 reveals the typical correct loop-curve but a decided loss in accuracy, which, if it had been perfect, would have brought each end of the curve to a point, whereas it is now dispersed over a distance corresponding to three piano-keys. (Comparison with the coördinated shifts in Chapter XIII will make this clear.) The amplitude of the curve points to tones of great intensity. This intensity resulted in spite of the fact that the subject making the record had been repeatedly told that speed was the only demand, and that a light stroke would facilitate speed. However, the operation of the principle of incoördination, analysed under Force Effects, Chapter IX, resulted in a complete reversion to type, according to which excess muscular contraction accompanied all attempts at speed. A similar excess in amplitude is seen in the record of the chromatic octaves, Fig. 155, in which the forward and backward arm-shift is almost double that of the coördinated movement, Fig. 156. The records for tapping, Fig. 96, furnish perhaps the most convincing proof of this correlation between slow speed and great amplitude in the incoördinated movements.

The use of the word incoördinated, in this sense, needs some defense. That speed and amplitude are correlated is a natural result of the principle of mechanics underlying movement. Any increase in speed, other things equal, means an increase in force, because the latter is equal to the product of the mass and the acceleration. The increase in muscular contraction which accompanies the attempt at speed thus becomes a coördinated reaction. But when it spreads to muscles that do not contribute to the movement it becomes incoördinated. In the lateral arm-shift of an octave, elbow-flexion and extension plus humerus rotation can readily take care of the horizontal displacement and wrist-flexion and extension of the vertical displacement. The *pectoralis*

major, controlling upper arm depression is not needed. When, as in the incoördinated movement, the entire arm is used, the momentum to be overcome at each end of the stroke is that much greater, hence demands an excess of muscular contraction to neutralize it. That is why all fast, very loud passages with change of direction can be played only with excess rigidity. Relaxed movement is there entirely out of the question.

But speed and lightness demand a higher degree of coördination than speed with force. The latter is usually restricted to one joint, the joints intervening between it and the point of tone-production being held fixed. The untalented pupil, therefore, naturally uses the latter. And, since the larger muscles are physiologically associated with forceful movements, such a pupil brings the larger parts of the arm or body into play, and never the smaller. Large muscles are naturally located more centrally in regard to the trunk, than small muscles ; or, the larger the muscles used, the greater is the distance from the joint at which motion occurs to the finger-tip, the point at which tone is produced. Consequently, the greater is the mass to be moved. Such a mechanism is at a considerable disadvantage when rapid changes of direction are needed, primarily on account of the momentum, which increases with each increase in mass. Moreover, where lightness is desired, the touch-form just described is useless. No mechanism in which the mass is great is adapted either to rapid changes in direction or to lightness.

This brings up again the question of gaining the same force by appropriate contraction of smaller muscles lying closer to the end of the finger. Granting that sufficient force could be secured, this would act upon a body of relatively small mass, hence inertia and momentum would be less, and a change of direction could be more readily made. Instances are found in the greater ease of hand-staccato for rapid, light, detached octaves, when compared with arm-staccato—or in the ease of finger-action, compared with hand-movement. The player whose finger and hand muscles are strong enough to give considerable dynamic range has an advantage over the player who uses his upper-arm muscles for similar dynamic effects, inasmuch as the speed of movement is not retarded by the larger mass of the moving part or parts. So long as the direction of motion does not demand rapid changes, this advantage is less helpful, but for movements requiring rapid changes of direction, minimal mass of the playing parts is essential. The purely gymnastic training of the small muscles of the fingers, hand, and fore-arm, in order to increase their absolute strength, is, therefore, from a mechanical standpoint, highly desirable for piano technique.

For all light work, and all speed work, light or heavy, requiring rapid changes in the direction of motion, the momentum of the moving parts should be as small as possible. This means that the smaller parts of the arm, rather than the larger parts, should make the movement.

This, of course, is not to be understood as a return to the pure finger-technique of fifty years ago. The use of the upper arm and of the shoulder muscles is at times both advisable and even necessary. But in recent years the pendulum has swung too far in the direction of weight technique, which, incidentally, someone has, quite aptly, labelled the " wait technique ". I have already pointed out the mechanical impossibility of using weight technique in any figure involving rapid movement-repetition, and in the chapter on Tone Qualities, its interference with all brilliance will be shown. These two phases alone should suffice to put us on our guard against the indiscriminate application of weight. Where slow speed and slow changes of direction permit its use, tone-production with the relaxed arm, in proportion to the dynamic degree, is to be preferred, both on account of the improvement in tonal quality (the noise-elements being largely absent) and on account of the principle of mechanical economy, there being a minimum of wasted energy. On the other hand, where speed and lightness, particularly speed and force are simultaneously required, there can be no talk of weight-technique or of relaxed arm. Isolation, instead of being aim and end of training, is just the opposite : a typical characteristic of incoördinated movement. When we have movement restricted to a single joint we have relative isolation. But in all the records given for coördinated movement, pure circular movements (the geometric projection of movement at a single joint) are conspicuously absent, whereas they are more noticeably present in the examples of incoördinated movement. And these centres of movement have primarily to do with the larger muscles, gross movement, and slow speed.

Fig. 158, which shows the curve of the centre of the hand for the first four measures of the Chopin Etude in F Major, Op. 25, No. 3, illustrates, once again, the substitution of the rotary motion for the angular. In this passage no stretch of more than an octave is found for any one beat. The movement, therefore, could readily be made without the rotation so far as stretch is concerned. The points marked *n*, *m*, represent the movement corresponding to the second beat in the first and second measures ; *o*, the last beat of measure three ; *p*, the last beat of measure four. The motion thus becomes elliptical and, as such, is a continuous movement

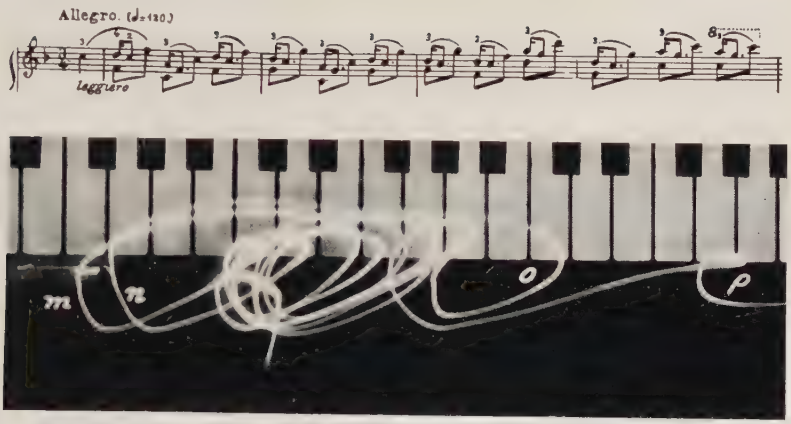

Fig. 158. Arm-rotation.

Fig. 159. Complexity of arm-movement.

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of the fore-arm and upper-arm, upon which the smaller movements of the fingers take place, without however, bringing the arm movement to a stop. This is in direct opposition to the type of movement which would move the hand and fore-arm to their positions exactly above the keys to be played. The absence of bright points of light in the photograph shows clearly that the speed of hand-movement has been but little retarded while the keys were actually depressed. Experiment has proved that, for a pupil possessing enough technique to warrant his approach to a piece of such difficulty, the movement shown can be made very comfortably at a much slower tempo than that prescribed. Practice may, therefore, begin immediately with the free-arm movement, as a result of which the learning process may be facilitated, the readjustments necessitated by incorrect early movements eliminated, and the practice time shortened. The objection that such movements are readily observed by the pupil or are explained by the teacher, is not true; the average pupil finds it quite difficult to observe the finer adjustments in a rapid movement, and the average teacher of advanced piano, unfortunately, seldom analyses sufficiently to know how or why he does a thing. Moreover, when he plays the passage slowly, his highly developed coördination, working on the principle of biological economy, adapts the movement to the slow speed and thus makes observation useless, by changing the nature of the movement.

I do not maintain that by simply keeping the geometrics of the movement the same, we likewise keep the mechanics the same. This is mechanically and physiologically impossible. What I believe is that the registration in the nervous system of a slow movement the geometrics of which are to be retained, may be a gain in pedagogical economy.

Fig. 159 illustrates the hand-movement in the given passage from the A minor Etude of Chopin, Op. 25, No. 11, measures 47 and 48 of the *Allegro con brio*. It brings to light, among other things, a noticeable forward and backward shift, which, incidentally, is present in all complicated passages, to an extent out of all proportion to the pedagogical attention such a movement has received. A glance at the other figures in this chapter will reveal this importance. For the sake of clearness, I have lettered a few points in the curve corresponding to similar points in the notation. From *m* over *n*, *o*, *p*, to *q* we have the typical arpeggio curve, modified somewhat by the mixed character of the particular figure. The forward shift to *r* was made to accommodate the thumb on F-sharp, that at *s*, similarly for B-flat. The many mixed curves,

in passing from *r* to *s* show a fore-arm rotation, a tremolo, in the playing of the second measure. Various features of the curve show the non-legato character of most of the figures. Thus the descending curve from *o* to *p* and *q* is very similar to the well-coördinated movement of the cadenza from Liszt's Lorelei, given in Fig. 152, which was a non-legato technique. Without this non-legato the above passage from Chopin becomes extremely difficult and results, at best, in an awkward performance.

When we realize that the camera has here caught only displacements in the two directions of the horizontal plane: lateral and forward–backward, and that to these, in the actual playing are added vertical displacements and many finger-actions, we can get some concept of the enormous complexity of the movements made in piano-playing. The relative absence of bright light-points in the curve corresponding to the arpeggio again shows that the hand was not held quietly until one figure had been played, and then shifted into the next octave, but that the lateral shift, combined with a forward and backward shift and, normally with some wrist motion, was going on steadily while the fingers were executing their own movements. Otherwise, bright points, as they are seen to some extent in the latter part of the curve, would be present. It is entirely possible to play the first figure with a quiet hand and thus avoid the forward shift beginning at, and returning to *m*; but this is not the manner in which the accomplished pianist plays the passage, although the excessive shift here recorded may result in part from the rather short thumb of the pianist who made the record. As before, the characteristics of this movement are non-legato and continuity; simultaneously with a relatively slow and fairly steady shift of the larger parts of the arm, the hand and the more rapid finger-movements take place. Mechanically the process is similar to the movements of a compound pendulum, the first bob of which moves in the simple pendular curve while the last bob may be moving in very complex curves.

In Fig. 160 is given the hand-movement for the last cadenza in the Chopin-Liszt Chant Polonaise: "Mes Joies." The entire passage could be played with a quiet hand, but the curve made shows a noticeable amount of forward and backward arm-movement. Even the mixed trill, with which the cadenza begins was, in this case, played with a shifting hand, else the bright spot at the beginning of the passage would be little more than a point. The slight forward shift at *a* accompanies the playing of the black keys, B-flat and A-flat. The more noticeable shift at *b* is caused by the A-flat in the next group, and the wide forward shift at *c*, by the use

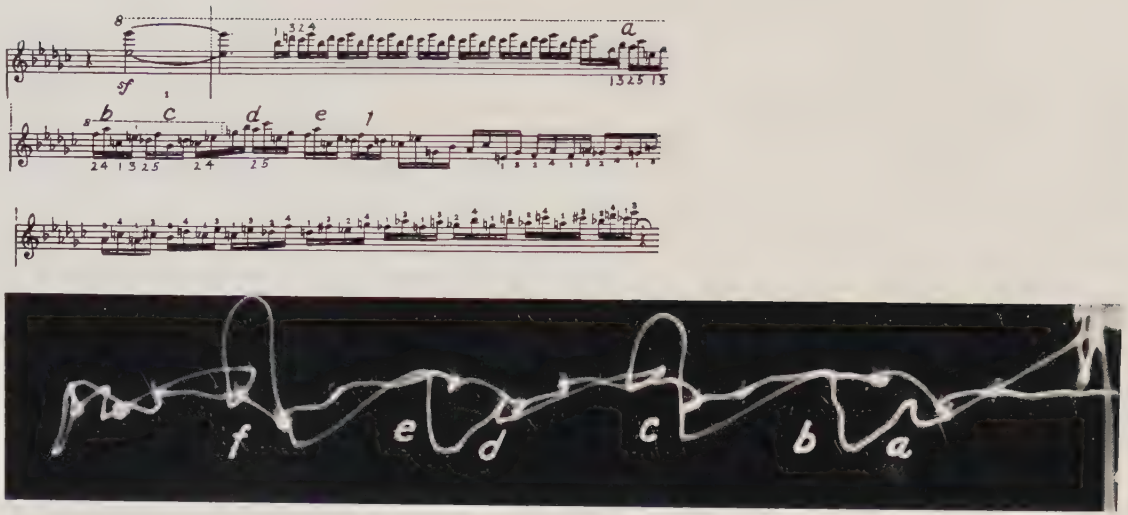

Fig. 160. Hand-shift, vertical view, for the given cadenza.

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PLATE XXXIII

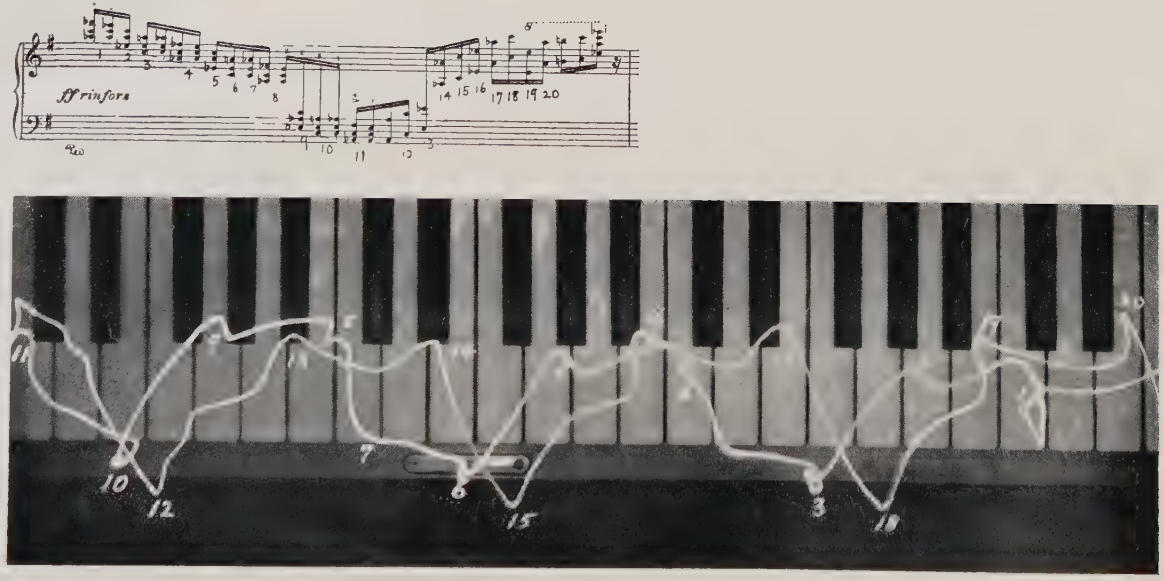

Fig. 161. Hand-shift for the given cadenza. Note amount of forward-backward arm-movement.

[To face p. 293

of the thumb on B-flat. These movements are then repeated in the next octave at points *d*, *e*, *f*. The ascending curve is much smoother, because the chromatic thirds are uniformly spaced. But even here, a forward shift of approximately one and one-half inches is present. The chromatic thirds may be conveniently played with a quiet hand but were not so done in this record. The movement was not restricted to finger-action plus a straight lateral shift of the arm, but the differences in black and white keys resulted in a forward and backward shift of the arm, as well. This, naturally, is much more marked in the descending part of the figure than in the ascending ; the chromatic thirds in the latter being entirely regular in their distance relationships. The slight forward and backward movements result from a slight raising and lowering of the wrist ; the small loop effects result from a lateral twist of the wrist necessary in double-note (and similar) passages to facilitate the legato. So that even in a passage that could be played with a quiet hand, we find the pianist using arm, fore-arm, and wrist movement as aids to the finger-movement.

In Fig. 161 the movement for the right hand in the cadenza near the end of Liszt's Tarantella : Venezia e Napoli is given.

The numbers given correspond to the similar numbers below the notes. Significant again is the amount of forward and backward shift both in the descending and in the ascending figures. The small loops show twisting of the wrist ; the forward shift, such as from 7 to 8, shows raising of the wrist. The total movement, therefore, combines arm, fore-arm, wrist, and finger movements in all dimensions : vertical, forward-horizontal, and lateral-horizontal. The flatness between 13–14, 16–17, 19–20, results from the muscular inhibition made to avoid contact with the fall-board of the piano. In the descending part of the curve the cumulative forward position of the hand-centre (compare 1–2 with 4–5 and 8–9) was caused by the rise in the wrist, as the right hand approached the bass region of the keyboard. The curve is further interesting because it shows that octave transpositions demand changes in movement. So far as the notes are concerned, we have exact duplications in three octaves ; the curve of movement, however, shows that the hand must make some adjustments : from 1 to 3 is not precisely the same as 4 to 6 ; from 3 to 6 differs slightly from 6 to 10. Similar differences will be found for other parts of the curve, as well as in the curves of other figures. It is, of course, inevitable that this be so, because the position of the shoulder changes in relation to the part of the keyboard being used. It is the experimental evidence of the fact already stated, namely :

that in any pianistic movement of moderate range or more, a constant shift of muscular coördination occurs which does not parallel exactly the notation or keyboard spacing of the figure. The A-flat chord is triplicated in the notation, but the muscular coördination responsible for the playing of the last (highest) octave differs quite noticeably from that responsible for that of the first (lowest) octave. This is inevitable in view of the extended range of the passage.

The foregoing list of miscellaneous movements, fragmentary as it is, suffices, nevertheless, to substantiate the conclusions reached in earlier chapters on the various phases of the mechanics of piano technique. In each case we find the entire muscular system of the arm at work, and in many cases, that of the shoulder as well. Any isolation of movement, therefore, must be understood as relative. The presence of arm-movement is not the result of the particular selections used, because we find the arm-movement present in passages the extent of which does not necessitate it. But it does not follow on that account that arm-movement is always advisable. In some instances it is used (as in single or double trills) to aid finger-movement, whereas sufficient drill in the finger-movement, granted, of course, sufficient kinesthetic control and speed coefficients, could and would make this aid useless. When and where the arm-movement is advisible has been mentioned in connection with the various touch-forms and the miscellaneous movements we have been analysing. If the older school of pedagogy, which insisted upon a rigid arm and quiet hand, erred on the side of too little movement, the modern relaxation school errs equally on the side of too much movement. Wherever speed and change of direction are rapid, reduction of the inertia of the playing-mass to a minimum is mechanically desirable. And, conversely, wherever tone, tempo, and direction permit weight-transfer, the arm may advantageously be used, because it facilitates tone-control and reduces the undesirable elements of piano tone-quality—the impact-noises—to a minimum.

On the other hand, the lack of isolation mentioned in the preceding paragraph, must not be interpreted as an uncontrolled shifting of muscular activity. In repeated movements it is mechanically desirable to repeat the coördination responsible for the movement. This, however, does not mean isolation of muscular activity; although it may well mean isolation of visual movement. It is not a mere coincidence that, in the many records made, the accuracy with which the moving parts retraced their paths in repeated

passages, paralleled, very closely, the so-called technical finish of the player. (See Figs. 211 and 212.) Poor technique was indicated in deviations from the path. Often these deviations were minute, and were not tonally noticed as deviations. Yet their frequent occurrence is one determinant of individual style, and helps to account for some of the differences noticed in the playing of one composition by various pianists. An interesting instance of the effect of movement-type upon technical and tonal value was unexpectedly disclosed in the recording of violin movements. A rapidly repeated passage was reversed, the player finding the result rather poor. The curve showed wide deviations instead of repetition. With a little practice the tonal result became satisfactory—and at the same time the curve showed the expected accuracy of repetition. This correlation is seen also in many of the illustrations already given, and it seems safe to conclude that technical accuracy in repeated movements depends upon spatial repetition of the movement. From a mechanical standpoint this is logical: the same mass moving in the same direction and at the same speed will produce exactly the same effect with each repetition. And, although the same effect may be secured in various ways or by various movements, the accuracy is often impaired when the muscular coördination is changed. The same weight "feels" quite different if lifted first with the finger alone, then with the hand, and finally with the arm. Where the passage demands exact repetition, it should be played, so far as possible with exact movement-repetition, which, in turn, means repetition of the muscular coördination underlying the movement. Instances are found in trills and arpeggios, and many scales, more specifically in parts of such works as Beethoven's Waldstein Sonata, Liszt's Waldesrauschen, Ravel's Ondine, or Chopin's Berceuse, in short in all figures used primarily for colour and not for rhythmic or melodic effects.

Such examples occur frequently, it is true, yet they are far less frequent than passages in which melodic and rhythmic demands obscure and modify exact repetition. This fact has led a prominent pianist, upon his being asked to play an absolutely even scale, to reply: "I have never played one." And certainly, in piano literature dynamically and agogically inflected passages are many times more frequent than uninflected passages. In preceding chapters I have attempted to show that each such inflection necessarily involves a shift in muscular coördination. The records of this chapter show such variations for each complex movement. Accordingly, in actual advanced playing—and, to a less extent

in elementary work—coördination is opposed to isolation, unless the latter be understood in so relative a way as to destroy the meaning of the word. If the movement involve any shift of the hand, or even of the thumb, or if it contain any crescendo, diminuendo, accellerando, or ritard, it will require a shift in the muscular adjustment, and only if the entire passage with its dynamic and agogic inflections be repeated, will the entire muscular coördination be repeated.

In piano pedagogy, attention should be directed to both finger-action and arm-movement. Finger-action with quiet hand is just as necessary for the perfect execution of certain passages, as the addition of hand- and arm-movement to this action is necessary for other passages. The older school of pedagogy did not countenance the latter at all; the modern relaxation and weight schools have failed to give the non-weighted finger- and hand-technique its proper important place.

CHAPTER XXI

Individual Differences: General

Thus far the analysis of the physiological mechanics of piano technique was directed toward establishing the general laws upon which such movements are based. The conclusions drawn from the investigations of the various problems, both mechanical and physiological, hold for any non-pathological case. But the problems of the piano teacher are not only general problems, they are also, and preponderantly so, specific problems. And against the physiological constancy set up in preceding chapters, we have now to place the physiological variability that gives rise to the important question of individual differences. Musical talent would have no intelligent meaning were it not for this variability, which reaches into the finest fibres of man's nature. It is responsible for the difference between John Smith and Paderewski, between *ein Bauer* and Harold Bauer.

As complex and subtle as individual differences in musical talent are—and ten years of experimental work in the analysis thereof have not lessened my appreciation of either their complexity or their subtlety—these differences, nevertheless, begin in the variations of the gross physiological organism: the size of the hand, length of the fingers or arm, weight of the arm, and range of movements. A detailed treatment of individual differences is impossible here—the question demands a comprehensive investigation as a separate problem. But an analysis of some of the important features thereof is necessary to show how the general principles deduced in earlier chapters cover the range of individual variation, and also to show how such physiological variations can account for the phases of mechanics yet to be discussed under Style.

With this plan in mind I shall treat, in a very brief way, the variations in arm-structure, muscular arrangement, circulatory and neural deviations. Then, in a separate chapter, I shall take up in a more detailed manner, variations in the hand itself, as being of greater direct interest to the piano teacher.

The Arm.

In the pedagogy of the relaxation or weight schools of piano-playing, the arm-weight is a factor of great importance, since it is this weight that is held responsible for tone-production.

The force which a falling body exerts (a necessary movement-condition if arm-weight is to be effective) varies with the weight of the body and the distance through which it falls. In analysing the effect of variations in arm-weight upon piano tone it is advisable to keep each of these two factors constant, while the other varies. The adult arm-weight, as common observation shows, varies considerably. Among my own pupils (excluding children) I have found a range between six and fourteen pounds, or 233°/₀, when the arm is supported immediately above the elbow. We have this wide range as one determinant of tonal intensity, a range sufficient to embrace several of the usual dynamic degrees.

The force of free arm-drop is considerably more than that needed for normal tone-production. But it shows a variation that is responsible for wide differences in tonal intensity. In other words, the production of a tone of a given intensity by an arm weighing six pounds requires a different muscular setting than that of a twelve pound arm. And, conversely, similar arm-conditions in such a case will result in noticeably dissimilar tonal intensities.

In support of the assertion that individual differences in arm-weight are an important factor in determining the easiest method of tone-control, see Fig. 162, which shows five arm-types : *a* is the arm of a relatively slender girl of thirteen ; *b* that of a male adult ; *c* that of a female adult ; *d* that of a girl of nineteen ; *e* that of a boy of nineteen. A glance at the pictures will show, better than words, the great variations in tone produced by arm-weight. The arms shown vary in weight from eight to fourteen pounds and in length from twenty-four to thirty inches. If we include a child's arm, the weight-difference will be still greater.

So far as arm-weight is concerned in tone-production, therefore, we may logically expect considerable individual variations in tone. If arm *b*, Fig. 162, is used for a given tonal intensity, arm *e* will produce a tone much louder. To produce the same tonal intensity either arm *b* will have to add muscular contraction to arm-weight, or arm *e* will have to restrict arm-weight by an opposite muscular contraction. This dependence of tonal intensity upon arm-weight, it seems to me, must be considered by a teacher who demands a uniform tone intensity (for similar phrases, of course) from all pupils, whether child or adult, light or heavy. At least the fact must be recognized that such uniformity is gained only by proportionate differences in muscular adjustment—in which case we cannot properly speak of arm-weight producing the tone.

The arm differences are so marked that they are probably generally accepted as one tonal determinant. But cannot similar

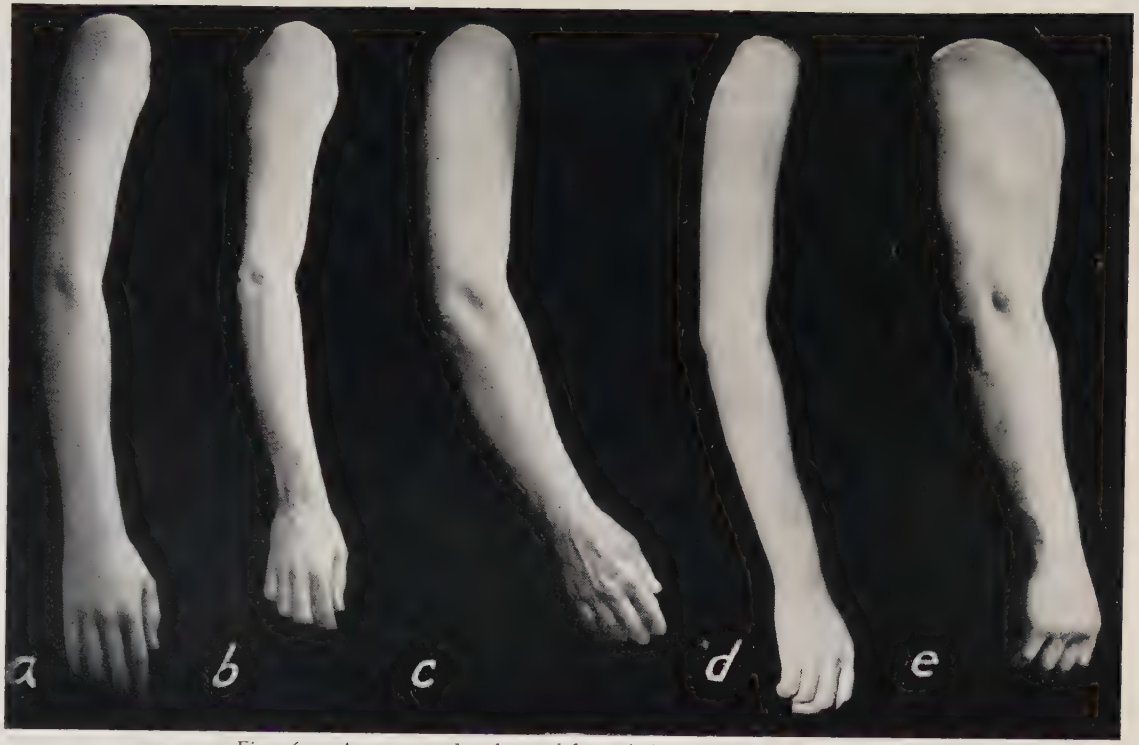

Fig. 162. Arm-types, showing weight-variations of two hundred per cent.

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hand- or even finger-weight differences account for smaller, less obvious, but none the less important, tonal differences ?

The weight of an adult finger varies approximately between one and three ounces. The normal curved-finger stroke is a movement of the finger-tip through approximately two inches. Moreover, if the free-drop be reënforced by equal muscular contraction, the force of the heavier finger will always be greater than that of the lighter finger, and the resulting tone louder. In order to produce equal tonal intensities with finger-stroke, the lighter finger will require more strength of muscular contraction than the former. True, the coördination may be shifted and hand-weight used ; but in a passage requiring rapid finger-lift or repetition, hand-weight is excluded (see Chapter XI) and the tone-production depends upon finger strength. It is for this reason that if a child, especially with a slender, light hand, is to play rapidly, a light tone is absolutely necessary until the muscular strength in the finger muscles has been developed. A heavier hand can play at the same speed with greater tonal intensity.

Similar differences are found when arm-, hand-, or finger-length is the determining element. The latter is discussed in detail in the next chapter. Arm-length, particularly in connection with the width and thickness of the trunk, determines the ease with which keys at the extreme region of the keyboard, when the arms are crossed, can be reached. Modern piano literature occasionally calls for a double *glissando*, beginning with the hands crossed over several octaves. A corpulent, wide-chested player, with short arms, may find such crossing in front of the chest quite impossible. The adult arms I have measured varied in length between 26 and 32 inches from arm-pit to finger-tip. The variation here is considerably less in relation to the modal arm-length than the weight-variation, but six inches is a considerable distance—approximately an octave—on the keyboard. A difference of an inch may mean a stretch difference of one key on the piano. In rapid leaps, such as the crossing of the hands—a typical technical stunt in many advanced etudes—even such a difference may be sufficient to interfere with the accuracy of the leaps. These, as we have seen in the chapter on Lateral Arm-Movement, are made normally by a free-travelling arm. Insufficient arm-length may require a leaning-over of the trunk, or greater force of throw to overcome the flesh, tissue, and skeletal resistance of a broad chest. A narrow-chested person, arm-length between 30 and 31 inches, can cross the arms simultaneously and cover a keyboard distance of approximately 30 inches or five octaves and a fifth or sixth. A stout person

has difficulty in covering four octaves. Again, an arm-length of thirty or more inches permits the playing of the keys of the highest octave with the hand knuckles parallel to the keyboard, the elbow being flexed between 40° and 50°; and, by leaning the body further forward, the angle may be increased to between 70° and 80°. The distance to the extremes of the keyboard, from the shoulder in an adult (height 5 ft. 10 in.), when seated in erect playing position, is about 29 inches, hence a short arm (for example, 27 inches) cannot even reach the last piano-key without a change in trunk position.

The effects within extreme ranges of the keyboard, though more marked, are of less practical importance than those closer to the middle range. Here the arm-position and, on account of it, the body-position, are frequently determined by arm-length. A long arm will require a greater distance between the seat and the keyboard. I recall a pupil whose arms were excessively long in relation to the other anatomical proportions. Only by permitting her to sit at what to all appearances was an absurdly great distance from the keyboard could I get a horizontal fore-arm in the middle pitch region without throwing the elbow too far behind the body. This arm-length, coupled with a relatively short leg-length, prevented any flexion whatever at the knee when the feet rested on the pedals.

Neither height of seat, nor its distance from the keyboard, can be fixed at any point. They should vary with the proportions of the trunk and of the arms. Thus the position of Rachmaninoff or Siloti will differ from that of Bauer or Novæs (a difference readily observed at a concert).

For teachers of children, anatomical differences are of great practical importance. Passages that are entirely impossible when fingered as an adult hand would finger them, become quite playable with appropriate fingering or division between the hands. Sliding with the same finger from black to white keys, division of the tones of a chord between the hands, playing of the thumb on two adjacent white, or even black keys, are cases in point. Many passages in Schumann, for example, which as printed, require stretches of a tenth with crossed thumbs, can be played much more easily by reversing the thumb notes; or, as at the beginning of Beethoven's Moonlight Sonata, by substituting 1–3–5, r.h. for the usual 2–4–5 given in the standard editions.

Muscles.

Individual differences in musculature are found not only in the strength of muscles, but also in their exact location, their

multiplicity of origin or insertion, and even in their complete absence. It is by no means beyond the realm of possibility that such differences play a part in establishing differences in the fundamental technique of individuals. Let us take, as an example, the short flexor of the little finger (flexor brevis minimi digiti). It is sometimes entirely absent, in which case the abductor of the same finger is somewhat larger than usual. But the movements of abduction and flexion are linearly at right angles. With two muscles acting, the little finger can be flexed more readily in an abducted position (as in extended chord work) than with a single muscle controlling both movements.

As a second illustration, we may take the *palmaris longus*, a slender muscle lying in the fore-arm. It is relatively often absent. Yet its insertion into the central part of the annular ligament and its expansion into the *fascia* of the palm, gives it a position very favourable in wrist flexion, such as that used in staccato octaves. Moreover, the insertion of the muscle is such that its interference with the action of other hand and finger muscles is relatively small, permitting, it would seem, freedom of finger movement during the flexing movement, a decided asset in many piano passages. Sometimes a second muscle parallels the first in function, structure, and position.

A third illustration of the effect of differences in muscular structure upon movement is furnished by the common finger flexor. This arises from a common source in the fore-arm and divides into four tendons. The tendon of the index finger is distinct (this accounts for the physiological hand division shown in Fig. 165*d*), the remaining three tendons are connected by tendonous slips. The extent of this connection, however, varies. Where it is limited, that is to say, where the tendons separate well above the palm of the hand, there is reason to believe that the separate movement (flexion) of the third, fourth, and fifth fingers is facilitated. This distinction must not be confused with the coördination resulting from practice.

The *pronator radii teres*, a pronating muscle in the fore-arm is still another muscle that is occasionally absent. Its work is then taken over by the other pronating muscles, but obviously at a different mechanical efficiency.

The list could be extended; what has been given suffices to show that individual differences in the mechanics of movement may result partly from the muscular and skeletal structure, because with each change in the angle of pull and the length of the lever-arm (see Mechanical Principles) comes a change in mechanical

efficiency. Concrete data on the effect of the details of muscular structure upon the finger- and hand-movements are difficult to obtain since the X-ray and surgical procedure are respectively useless and impossible. But knowing the mechanics of the muscular action and the positive variations in musculature, we may safely infer that some differences, even if only slight, in the natural capacity for coördinated movements, may result from the details of muscular structure and position such as we have been considering.

Strength.

Closely correlated with this difference, is that in the actual strength of muscles. In the case of hand-grip I have found variations over a range of a thousand per cent between the ages of seven and twenty. Is this to be expected? Then let us expect similar differences in the strength of the smaller finger and hand muscles, and allow for them in the production of tone upon a mechanically fixed keyboard. When a child produces a singing tone on the piano, he does so with a muscular coördination quite different from that used by an adult for the same tonal intensity. And, conversely, when a child restricts movement to a finger-stroke, he will produce a tone far different from that produced by an adult with the same coördination. Variations in the strength of finger-flexion (the movement for tone-production in the piano) extend from a few ounces to several pounds. I know of no case of adequate piano technique accompanied by finger weakness. In fact, I am convinced, after measurements on this phase, as well as general observation of pupils, that much of the limitation of girl and women players results from an inadequate muscular strength, in fingers, hand, and arm. As a concrete example I cite the case of a girl of fourteen who, with all the speed and accuracy necessary for *bravura* octaves, cannot take them beyond a moderate *forte* because the fifth finger cannot sustain the force. Careful observation through a number of years is showing the entire dependence of this phase upon the strength of the flexor of the fifth finger.

In other words, technical clarity and efficiency are not entirely a matter of coördination, but are determined, far more than is generally believed, by differences in the strength of the muscles involved. The fact that the hands of some pianists are soft to the touch, and those of others are firm, is not an index of muscular strength. The soft hand can readily result from good relaxation, which, we as have seen, is prerequisite to proper coördination. Such a hand can at a moment's notice contract into a firm position,

by appropriate muscular contraction. And it can, with equal rapidity, relax again. In fact, in this immediate relaxation, after the need for fixation is over, we find one important element of kinesthetic talent.

Detailed instances of the effect of finger and arm strength are given elsewhere, under finger-stroke, tremolo, vibrato. At this point the effect of strength is listed merely as one determinant of individual differences. It demands that a tone-production be used commensurate with the strength value, if the coördination is not seriously to be interfered with. After all, does not the adult teacher, when listening to a small pupil play, too often image the tone-values he himself would produce, instead of those he would have produced at the child's age? And then, when the child necessarily stiffens in order to meet these demands, does not the teacher too often complain about the stiffness? Or, if the pupil adopts the skeletal hand-position shown in Fig. 187, in order to transmit the necessary force to the keys, or uses the side of the hand to accent a high pitch with the right hand or low pitch with the left-hand (see Fig. 166), does not the teacher complain about high-wrist or the slant toward the fifth finger, because his own stronger hand does not need either position?

A few concrete instances will show the practical effect of strength variations such as we have been considering. Strong fingers can play in flat position and yet produce sufficient tonal intensity. The correlation between flat fingers and extended broken-chord figures is discussed in detail under Arpeggio. Weak fingers cannot possibly play such figures rapidly and clearly, the intermediate notes are almost always skimmed over. Strong fingers are needed for all rapid *forte* scales, since arm-weight cannot be transferred beyond the five finger limit. (See Chapter XI, under Thumb-Movement.) Strong fingers reduce the tendency to stiffen because the insertion of the *lumbricales*, one of the finger flexors, is in the hand itself, hence the tendons of these muscles do not cross the wrist, and, accordingly, do not require fixation of this joint to transmit their pull. Just as soon as we use arm-weight, this fixation is necessary. The dynamic inflection of most trills, particularly any double trill, is entirely dependent upon finger-strength; arm-weight is out of the question. (See Trill.)

As much as I am opposed to mechanical appliances in actual piano practice, since I believe the association of the physiological movement with the tonal result is absolutely necessary, so much am I convinced that the mechanical strengthening of the finger and hand muscles through appropriate non-pianistic exercises is necessary.

The piano keyboard, and the essentially percussive nature of piano touch, as well as the position and *modus operandi* of the muscles themselves, are not well adapted to a rapid muscular development. By a systematic training of finger and thumb movements, with appropriately controlled resistances, the hand muscles, upon which the brilliance in many piano passages depends, can be strengthened in a much shorter time. Moreover, the " mechanical " drill at the keyboard, with which many pupils waste an enormous amount of time, can profitably be detached from tone, so long as its function is mechanical. Then, perhaps, keyboard work will be less mechanical.

Pathology.

Individual differences in movement and in the naturalness of various hand-positions, can be studied by an analysis of certain

Fig. 163.

pathological conditions. When the ulnar nerve is injured, a paralysis of the muscles in the palm of the hand (lumbricales and interrosei) results. The hand assumes a marked claw-like position, Fig. 163. The similarity of this position to that in Fig. 16*a*, the typical, " broken arch " position of piano pedagogy, is striking. It proves, rather conclusively, that the maintenance of hand-arch depends upon the two sets of muscles mentioned. Such a case of paralysis is extreme, and the resulting hand-position (it is often more marked than Fig. 163 shows), is caused by the pull of the extensors, which is then not offset by a pull of the antagonistic flexors (see Tonus). But, suppose that a weakness of the muscles exists instead of complete paralysis. Then the greater pull of the extensors would cause a partial depression or flattening of the arch, a tendency characteristic of quite a few pupils. Or reverse the supposition, with the flexors as the stronger group. Such a hand

would find it difficult fully to extend the fingers. As a matter of fact, the deterioration of the *palmaris longus* muscle has at times resulted in a thickening of the *fascia* of the palm with permanent flexion of the fingers, the condition being known as Dupreytren's Contracture.

Non-Pathological Differences.

Thus the natural hand-position of an individual pupil may be partly determined by the balance of pull of the various antagonistic muscle groups. The mere maintenance of proper hand-arch by pressure upon the piano-key is not sufficient, because the arch can be forced up by pushing the elbow toward the keyboard, which is the work of the shoulder muscles. Exercises, such as squeezing a rubber ball in the hand, illustrate the proper functioning of the muscles. Such resistance is not present in the keyboard, and can best be applied by mechanical devices. Pressure upward, on the under-surface of the fingers, immediately in front of the hand-knuckles, is effective in strengthening these muscles.

Similar conditions may exist in any other group of muscles. They account for the fact that pupils of small stature can often get marked tonal climaxes upon the piano. I know of a case where a girl of ninety pounds played the *fortissimo* passages of Chopin's F-sharp minor Polonaise at an intensity that would have done credit to a person almost twice her weight. True, the fixation required resulted in the bursting of a small bloodvessel in the neck; a very concrete illustration of the spread of fixation to remote parts of the organism.

Such physiological differences affect piano technique directly. In the case of the strength of finger-muscles, they can determine the height of finger-lift needed to produce tones of a certain intensity. With a range in finger strength of several hundred per cent, the requirements of finger-lift are proportionately variable. A finger whose flexor muscles are half as strong as those of another finger, assuming the masses of the two fingers to be equal, and ignoring gravity, will require double the finger-lift, other things equal, of the stronger finger. In other words, in order to produce the necessary finger velocity the weaker muscle must act through a distance twice as great as that required by the stronger muscle. Excessive finger-action, or even pronounced action, is opposed to smoothness, both on mechanical and physiological grounds. It intensifies the percussive element, which interferes with tone-control, and it introduces physiological strain, by exceeding the mid-range of movement (see p. 32). A sufficiently strong hand

can play diatonic passage-work at a fairly good intensity without finger-lift, restricting the finger to key-depression. A weak hand playing the same way " blurs " the passage and plays clearly only when a marked finger-stroke is used. Anatomically the hand-muscles are adapted far more for speed than for force, as Fig. 18, and the angles of pull of Fig. 103 show. Accordingly, their strengthening by appropriate exercise is pianistically advisable. It is this weakness that probably started the application of arm-weight as a substitute. But this can be used only to a limited degree. The mechanics of movement point out quite unmistakably the need for a strengthening of the smaller finger and hand muscles themselves instead of a shift into the larger arm-muscles as prime movers.

The effect of strength and anatomical build is seen whenever we group a sufficient number of individuals to show central tendencies. Then it is found that :—

1. Boys, as a whole, play more loudly than girls.
2. Strong and heavily built children and adults play more loudly than those weak and of light build.
3. Those tone-qualities associated with pronounced tonal intensities, such as brittle, hard, metallic, brilliant, are more frequently found in strong players than in weak.

The numerous exceptions which will immediately come to the minds of experienced teachers do not invalidate these tendencies. Any large unselected group will prove them.

Two quasi-pathological conditions are met frequently enough to warrant their mention here : the snapping of finger or wrist-joints and the formation of cysts. The snap is usually not accompanied by pain of any kind, but what it lacks in physical pain it often contains in mental anguish, especially for those persons who feel a violent aversion to the sound. The snap is most often caused by the sudden slipping of the head of a bone over the base of another. Consequently, the sound is increased if the two bones are pressed together with outside aid—the familiar " stunt " of persons who like to demonstrate their cracking potentialities. Any irregularities in the articulating surfaces will result in some noise ; and considerable play in the joint (the " double-jointedness " described elsewhere) permits irregularities in gliding, which in turn, may produce the snap.

The cysts are formed by the oozing out of the synovial fluid through the sheath of the tendon. Wherever a tendon passes over a ligamentous slip or bone, with a change of direction, it normally glides within a separate sheath which is lubricated by the synovial

fluid. If, for some reason, this sheath is ruptured the fluid oozes through into the adjoining fleshy parts, usually hardening into a spongy mass. In pianists this most frequently occurs on the back of the hand near the wrist. The particular location is of practical importance. If the cyst presses against a nerve when the fingers or a particular finger is used in playing, the condition may become acutely painful. Such a case has come to my attention recently. So long as rapid octaves were avoided no pain was felt by the pupil; but each time drill in octaves was begun, pain quickly developed, and necessitated a complete "lay-off" for several days.

Removal of the cyst by either the older method of spreading the accumulation by a forcible blow with some flat object, such as a book, or by surgical procedure, is not to be recommended off-hand. The value of such a procedure depends upon the cause of the cyst. If the cyst is caused by friction of the tendon over some projecting bone during normal movement, the removal of the cyst will not remove the cause, and when the pupil returns to practice, another cyst will, in all probability, form. However, if the cyst be caused by an unusual strain placed upon the hand—a severe blow or sprain, the removal, always of course by a very competent surgeon, is to be recommended. Tightly bandaging the affected part frequently relieves the feeling of pain or strain during subsequent use, but creates an artificial playing-condition that is of doubtful value if prolonged. Statistics seem to indicate that heredity also is to be reckoned with.

Circulatory.

The direct and very important effect of circulation upon muscular movement has already been noted in the case of Renaud's disease. Between this extreme—the complete inhibition of circulation in the arterioles and capillaries of the fingers—and the normal circulation are many intermediate degrees of blood-flow. If extreme constriction is followed by complete loss of sensation in the affected parts, the conclusion follows that a partial constriction will be followed by a reduction of the sensitivity. Examples of variation in blood-flow are: the warming-up exercises of all athletes and instrumentalists. The former go through the gross motions of their respective activities; the latter secure the result by washing their hands in warm or hot water; by rubbing them together and working the fingers vigorously; or, like Paderewski, by thundering out a series of massive chords. All these devices have for their aim an increase in the circulation and heightened sensitivity to reaction in the parts to be used.

Not only does the normal circulation differ among individuals, but the degree to which it can be changed, by exercise or emotional activity, varies also. The effect of cold, clammy hands upon piano-playing is well known to all teachers. The connection between such physiological states and the concomitant emotional states has been established by experimental physiology. Under the circulatory phases, comes the increase in the rate of blood-coagulation during emotional stress and the marked increase in blood-pressure. The latter may even reach a fifty per cent increase over normal, the amount varying considerably with the individual.

Here, then, are circulatory factors that may help to account for individual differences in pianistic performances. Anemia, for example, is always a limiting force in muscular activity of any sort. It is a condition of sub-normal presence of red blood-corpuscles, and hence of oxygen-carrying devices, with the necessary lowering of muscular activity. The extreme pathological cases are obvious enough, but the undesirable effects of moderate anemia are not often detected. It would be wrong, however, to ignore their influence entirely.

Neural.

Individual differences in the structure and function of the nervous system are of no less frequent occurrence than in the physiological fields we have just considered. There is, for example, the variation in the number of muscle fibres innervated by a single motor neuron, which covers a range of more than eight-hundred per cent among the various muscles of the body. Then there is the rate at which the neural impulse travels, which varies not only between animals of different species, but among animals of the same species, though here to a less extent. Finally, we must add to these variables the refractory phase of the synapse. The junction of two neurons is effected by means of end-arborizations : a very fine net-work of fibrils (axons and dendrites). After the passage of a neural impulse, the synapse requires a certain amount of time (normally a very small part of a second) to recover fully its transmitting power. The rate of this recovery varies among individuals.

Then, too, in spite of the enormous richness of association fibres, always present, there is yet room for considerable further individual variation. An interesting example of this is furnished by the synesthetic subjects, in whom sensations in one sense-department call forth, quite directly, sensations in other senses. Thus a tone will cause an image of a colour, or the reverse. (I do not include the extraneous experience associations here, but only the physiologic

synesthesias.) Such variations in association fibres could readily account for variations in the speed, delicacy, and accuracy of muscular movements. In fact, this seems to be the field that may explain not a few problems of variations in piano technique. Being neural it is primarily a psychological question, although its effects upon the muscles and the movement fall under physiological mechanics.

Metabolic.

Finally, in order to show how individual variation is still further determined by physiological structure, we may add a few results contributed by experimental physiology in the field of metabolism.

Strychnine, for example, effects the neural system by obliterating the differences in the resistances of the synapse. As a result, the indiscriminate spread of neural activity to the muscular system in general brings about the familiar strychnine convulsions. Alcohol reduces the degree of the psycho-galvanic reflex. The connection with emotional states in both cases is a matter of common observation. Arsenic is used as an alterrative : changing a morbid state into a healthy one. Blood-sugar is directly affected by emotional conditions, through the adrenalin secretion. A pupil who chanced to be examined shortly after piano examination was diagnosed as a probable diabetic until the surplus sugar was shown to be the direct result of the preceding heightened emotional stress. Furthermore, when the adrenal gland is stimulated, an improvement in muscular contraction follows ; and the converse of this is seen in Addison's disease (a disease of the adrenal glands), the most marked characteristic of which is muscular weakness. When extract of the glands is introduced, both the amount and duration of contraction of skeletal muscle are increased. In this chemistry of muscular action we have still another source of individual differences.

In fact, it is well within the field of probability that the muscular inhibitions which piano pupils frequently experience under conditions of emotional strain (examination or concert) are caused by chemical changes in the psycho-physiological organism. The connection holds for all emotional states, which, we have reason to believe, are little else than the actual physiological changes. In popular parlance, these are supposed merely to accompany the emotional states. The feeling of limpness or muscular weakness which frequently precedes a public performance can possibly be brought about by an inhibition of the functioning of the adrenal and correlated glands.

A combination of such circulatory, neural, and chemical variations

can account for many of the variations among pupils and within the individual pupil. Two facts necessary for this conclusion have already been established : the direct effects of such changes ; and the varying degrees in which the neural, circulatory, and chemical components are actually found in the human body. Investigation of these phases, with sufficiently sensitive apparatus, is an interesting field for the psychologist of music. The inference from even the cursory exposition just made is safe, that : a proper functioning of the used parts is a physiological necessity for proficiency in technique. Other things, of course, are necessary as well, but a poor functioning of the physiological organism is a real limitation. The many pathological examples : Mozart, Chopin, Schumann, Wagner, and others, do not invalidate the statement. In such instances the well-known compensatory reactions of disease complicate the result. In fact, the direct connection of emotional states with physiologic abnormal function—the hyper- or hypo-secretion of the glands, and the resulting abnormal chemical reaction—is, in such instances, evidence in support of the statement.

CHAPTER XXII

Individual Differences: The Hand

The spatial relationships of the keyboard are fixed. The keyboard distance between the two specific tones of any given interval is a constant. Accordingly, any variability in the stretching thereof must be in the playing hands. The fundamental space-relationship which we have to consider is that of the straight line as the shortest distance between two points. In all stretches the fingers necessarily strive for straight-line positions. But to attempt to force all hands into one standard position—the normal arched position—a position, by the way, that is not even a physiological norm (see Fig. 16*b* and Fig. 165 B) is seriously to restrict pianistic freedom and, in my estimation, is unwise pedagogy. It is as if we obliged each person to walk with a step of standard length, regardless of the length of the leg. The difference here is gross, but in the fine adjustments used in piano-playing even the slightest restriction is a hindrance.

The dimensions of the keyboard and the manner in which composers have written for the piano are such as to make the stretching of the necessary distances a problem for even normally full-grown hands. Such stretching is primarily a question of finger-abduction—the spreading of the fingers. Assuming A–B as a given keyboard interval and A–C and B–D as lengths of fingers, the lines in Fig. 164 show the different angles of abduction required for various widths of hand. A hand-width of C–D enables the player to reach the desired keys with parallel fingers and no angle of abduction or spread. If the hand is narrower (E–F) and finger-length the same (B–D = B–F = B–H) the hand must be moved slightly forward and the fingers spread into the angles A–E–F and B–F–E. A still narrower hand (G–H) moves the hand further forward and demands an excessive angle of abduction A–G–H and B–H–G. Wrist-position, also, is frequently influenced by hand-formation. When, now, the fingers are short, the hand narrow, and the angle of finger-spread limited, it is physiologically impossible for such a hand to reach wide intervals. Shortness of fingers may be partly overcome by breadth of hand, or width of the abducting angle, or by both. Likewise, narrowness of hand, or smallness of

the angle of abduction may be helped by the length of fingers. The three physiological determinants, therefore, of adaptability of the hand to the keyboard stretches are : length of finger, width of hand, and the angles of abduction among all fingers. In adult hands a third-finger length (measured from the knuckle) of 3 inches is subnormal ; 3·5 to 4 inches normal ; over 4, supernormal ; hand-width, measured across the hand-knuckles, exclusive of the thumb, 3 to 3·5 inches subnormal ; 3·5 to 4 inches, normal ; over 4, supernormal. The angle of abduction varies with the finger used, the second and the fifth fingers having the greatest range, the third next, the fourth least. This, it will be noticed, is in entire agreement with the physiological subdivision of the hand made in Chapter III where it was deduced from the anatomical structure

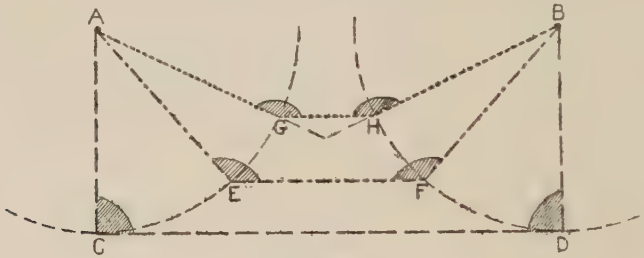

Fig. 164.

of the hand and its muscles. An approximate table of abducting values is :

Finger.	*Subnormal.*	*Normal.*	*Supernormal.*
2	25° to 35°	36°–45°	46° to 55°
3	20° to 25°	26°–33°	34° to 40°
4	10° to 18°	19°–24°	25° to 35°
5	30° to 37°	38°–45°	46° to 60°

A study of the foregoing relationships reveals also the advantage of the wide over the narrow hand. (Compare angles A–E–F and B–F–E, Fig. 164, with angles A–G–H and B–H–G.) The latter necessarily uses greater spread of fingers, and thus increases the difficulty of flexing the fingers, since flexion and abduction are in at least moderate physiological opposition. (See p. 45.) So that, while a narrow hand may succeed in making the stretch, freedom of playing individual keys in the stretched position is restricted. In fact the three factors of hand-width, finger-length,

and finger-abduction, to which, of course, the similar thumb values must be added, will explain a surprisingly large number of technical difficulties that are often wrongly attributed to defects of co-ördination or studentship.

Among these, as a conspicuous example, is the hand-position adopted in octave work. If the octave stretch is insufficient, or just possible, the pupil plays against the outer edge of the white keys instead of on their top surface. The playing on the edge does not require any bending-in of the tip of either the thumb or the little finger, nor does it require an arched hand, and a slight gain in spread is the result. Such a position, however, is impracticable in the playing of any rapid octave passage. I know of numerous instances where diminutive hands definitely terminated musical careers.

The same may be said of the high-wrist position frequently adopted by pupils with small hands. Here the thumb plays with the wrist almost over the keys. The bending-in of the thumb-tip is not necessary in this position, hence there is, as before, a slight gain in the distance between thumb and fifth finger. At the same time such a position necessitates an excessive extension of the middle fingers, lest these strike the keys within the octave. Both positions are make-shifts of the small hand. In many instances they are the only means of playing the desired passage at all. And in both cases the octaves are played from the shoulder or elbow, according to the pitch of the passage, instead of from the wrist. Usually brilliance in extended work is absent. Every now and then, however, a pupil gifted with a finely coördinated kinesthetic sense can develop an effective octave technique with these fore-arm octaves, and we have then an instance where that phase of style has been determined by the physiological structure of the hand.

Differences in adult hands, such as we have been considering, find a parallel in the differences among the hands of children of various ages and growth. These should be carefully considered in the assignment of work, permitting wide variations in the manner of playing or fingering a passage in order to adapt it to the physiological nature of the hand. For of all physiological instruments of movement, the hand with its appendages is by far the finest. The twenty or more joints and nearly thirty bones that make up its structure, and their manipulation by over thirty muscles make possible very fine adjustment of movement and help to account, among other things, for the surprising dexterity of many pianists.

In the chapter on The Skeleton a normal hand-position was deduced from the ranges of movement at the various joints, and normality was defined as a position near the middle of the range of movement. When the hand as a whole is considered, normal position may be defined as that position assumed by a body when in a passive state. The hand is in such a state in normal walking. Here it does no work and consequently is held in the position of greatest ease—its natural or normal position. If now, the deductions from skeletal structure are true, we should expect to find the typical hand-position in walking, whenever the attention is not drawn toward the hand. The hand, then, not holding any object, hangs freely from the arm. With the object of learning the per cent of the frequency with which the normal hand-position, and any other typical forms, might occur, I counted and classified the hand-positions of fifty thousand persons. The observations were made upon the streets of various cities ; they included standing, and walking subjects ; men, women and older children. When a hand was in active motion (not the passive pendular swing of walking), or carried any object, it was not counted. The counts were made at random intervals in groups varying from fifty to several hundred and the results separately tabulated. This procedure was necessary so that the constancy with which the percentages recurred in each group could be determined. The groups of course, were unselected, save for their urban character, representing merely the persons I passed on the street.

Fig. 165 shows the various types of hand-position which this observation revealed. A is a position of moderate flexion increasing slightly from the index to the little finger, side view ; B is the same position, dorsal view ; C, a position in which the fingers are over-flexed, while thumb is extended ; D, a position showing index isolation ; E, a position showing extension of the second and fifth fingers ; F, extension of all fingers. A and B, therefore, represent the normal position just described. C shows the isolation of the thumb (and A also). A, B, D show the isolation, or fundamental separation of the index finger (this being the only finger the nail of which is visible), the next physiological division after the thumb (see p. 44) ; E and F also show the fifth-finger separation. Accordingly, we should expect to find positions A (B) present most frequently.

The actual distribution found in the observations made was as follows :—

When the groups were averaged : Type A or (B) and D yielded

Fig. 165. Typical hand-positions, showing effect of normal physiological structure.

Fig. 166. The " natural " hand-position at the keyboard.

Fig. 168. Hypo-flexion of the nail-joints.

[*To face p.* 314

87 per cent; type E yielded 7 per cent; type C yielded 2 per cent: type F yielded 1 per cent. Another type (with clenched thumb, instead of extended) yielded approximately one per cent, while the remaining two per cent were distributed among various miscellaneous types, transient positions difficult to classify. When observations are combined in groups of 500, we find that types A and D varied in frequency between 74 and 93 per cent; type E between 3 and 12 per cent. The variations in the frequency of the remaining types are negligible. Two phases of this distribution stand out clearly: first, the marked preponderance of positions A and D, the normal position, over all other positions, alone or in combination; and the greater frequency of position E in relation to all other positions except the normal; and secondly, the constancy of this frequency shown by the low coefficient of variability.

The question now arises whether we have the right to apply this normal position of a vertical arm to the horizontal position of the hand required in piano-playing. The only real difference would be the action of gravity. If this were of sufficient force to affect the finger-positions, then, since it acts vertically downward, the fingers would be fully extended in a hanging hand. This, however, is not true: gravity is actually resisted slightly by the partially flexed fingers. This gives as the normal passive hand-position that shown in Fig. 165 A and B, which, when applied to the keyboard, will appear as in Fig. 166. Mirrored projections are included to show the position from various angles. The experienced teacher will at once recognize here the typical keyboard position of the untrained child. The hand-knuckles slant toward the fifth finger, and the fingers in consequence stand at a slant to the vertical line of key-action. The flexion increases as we pass from index to fifth finger.

The frequency of position E, Fig. 165, also points to this form as typical or natural particularly because some extension of the index finger is present also in type A. Additional proof of this is found in the naming of the second finger as "index" finger (German: Zeige-finger) as well as in the general representation of a hand by the anatomists, who give usually a fully supinated hand as one standard form, and an extended index finger, with other flexed fingers (position D, Fig. 165) as the other typical form.

The few instances of separation of second and fifth fingers (position E, Fig. 165) have their explanation in the fact that the greater freedom of the fifth finger is essentially concerned with the muscles forming the hyperthenar eminence, hence having to do with

increased flexion, rather than extension. We do not find the fifth finger extended alone on that account. On the other hand, these muscles explain the greater curvature of the fifth finger when compared to that of the third, in the normal hand-position, and also the curvature of the fourth finger which is flexed through tendonous attachment, sympathetically with the fifth finger.

The negligible frequency (less than one per cent) of a fully extended hand is especially interesting, in view of the fact that piano teachers find it necessary constantly to work against "flat fingers", and yet, naturally, fingers are not held flat, but moderately curved. The tendency of beginners at the piano to flatten (fully extend) their fingers (see Fig. 165 F), accordingly, cannot be explained as a natural physiological finger-position, but as the result of the application of the hand to the keyboard. The striving for a straight-line position, pointed out in an earlier paragraph, means that any attempt at stretching will cause extension, and insistence upon high finger-lift may do so likewise. In stretching, extended fingers cover a greater range than flexed fingers; and in the lifted position the tips of the extended fingers are higher than those of flexed fingers. It is entirely natural, therefore, that the child, with the aim of the movement maximum stretch or lift, should extend the fingers. Non-stretching exercises and moderate finger-lift are valuable aids in eliminating or avoiding the so-called flat fingers, to say nothing of their aid in avoiding stiffness.

All this has its explanation in the basic physiological function of the hand: the grasping movement and its negative opposite, release of the grasped object. In its natural form this movement involves simultaneous flexion of the thumb and of all the fingers, and hand-release likewise involves simultaneous extension of thumb and fingers. The physiologically simplest finger-stroke, therefore, is a movement in which the fully extended finger is flexed at the hand-joint, while flexion at the two finger-joints brings the tip of the finger against the middle of the palm of the hand, which is the movement made in grasping a small object. It is similar to the form of finger-stroke used in playing a rapidly repeated tone. But it is not the finger-stroke that modern pedagogy has found best for practical purposes. To meet these demands a vertical descent of the nail-joint is required. Such a movement, as a study of the figures in Chapter XVII, showing finger-stroke, will reveal, can be made only if slight extension at the two finger-joints accompanies flexion at the hand-knuckles. In other words, it is a coördinated movement differing from the physiological grasping reflex. The difficulty for the beginner is in this simultaneous

flexion and extension of the various finger joints. By directing the pupil's attention in turn to these two basic conditions of the movement, the natural general flexion may be overcome. In this connection, I have found it helpful to let the pupil start with the finger-tip as nearly against the ventral surface of the hand-knuckle as possible, and to aim for the end of a black-key, instead of a white

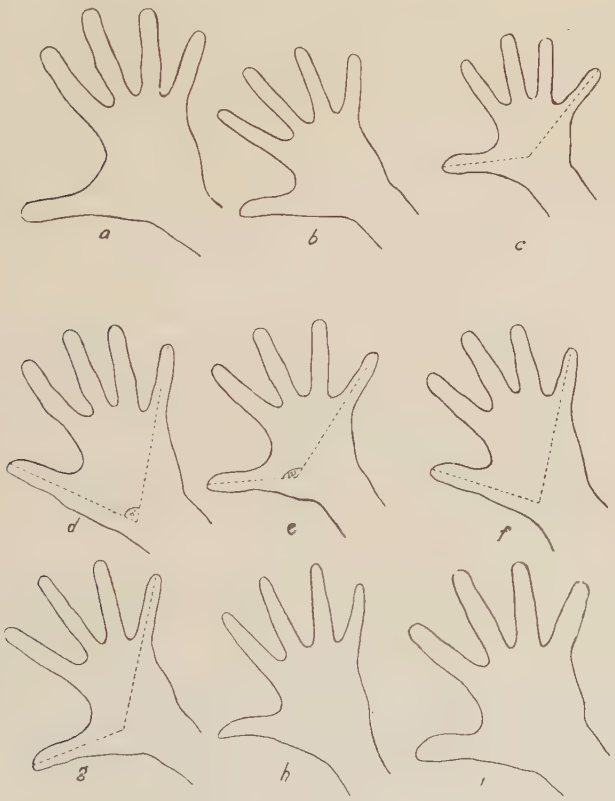

Fig. 167.

key. Thus the pupil starts with the two finger-joints in a position of extreme flexion, while the hand-knuckle is in a position of extreme extension; and ends with fully extended finger-joints and reasonably flexed hand-knuckle. The differences are thus magnified for the pupil, in accordance with the pedagogic principle of intensive presentation as an effective means of retention.

The physiologically natural hand-position is that shown in Fig.

166 and it is the object of piano pedagogy to adapt this form, so far as possible, to the technical demands of the instrument. Such a position is preponderantly normal, as the percentile distribution given on p. 315 shows, and individual differences here stand at a minimum. I have yet to find a single pupil, if he has never played piano or watched trained hands play, who will not place his hand upon the keyboard as in Fig. 166, so long as nothing is said to him about hand-position. Individual differences appear, however, once we have secured the horizontal hand and begin work with size and proportion of hand-parts.

Individual differences in the various parts of the hand are seen most clearly when the hand-types are pictorially presented. Fig. 167 illustrates some of the differences we have been considering. The scale of reduction for all the types is the same, therefore the relative sizes remain as they were originally. The pantograph illustrations are taken from direct tracings of hands.

Differences in the size of hands are strikingly shown in *a*, *b*, *c*. *a* and *b* are both adult hands yet the difference in size is greater than that between *b* and *c*, *c* being the hand of an undersized boy of nine years. To expect hand *b* to adopt and use in piano-playing a technique the same as that used by *a* is to expect the impossible. I do not refer here merely to the most obvious differences in stretch but to the entire technique. The degree, for example, to which arm-motion will and should supplement finger-action will differ radically between the two. Since both are adult hands, and both have had similar amounts of training, we cannot obviate this difference by an appropriate difference in the ease of assignments. Instead, the hand-difference demands a difference in style, which, as a matter of fact, is clearly evident in the playing of the two pupils.

d and *e* show differences in the angle of abduction between the thumb and the fifth finger. Type *d* shows approximately the lower limit, 75° ; *e* shows a fairly high angle, 127°. Although *d* is a much larger hand than *e*, the stretch between the tip of the thumb and that of the fifth finger is more than one-half inch greater for the small hand, a difference of one piano-key. In *d* a line connecting the tip of the thumb with that of the fifth finger will cut the three intervening fingers well above the hand-knuckles, while in *e* a similar line cuts the palm of the hand. These differences in the proportions of the hand naturally make for differences in the pianistic use of the hand. Hand *d* is pianistically at a marked disadvantage.

f and *g* show the difference between a decidedly unfavourable

hand and a very favourable type. The former is handicapped by a short stretch between thumb and index finger; very high webs between 2 and 3, and between 3 and 4; generally massive and stiff build for a child's hand; small angle of abduction between 1 and 5, and small range of movement at the wrist. *g* is the hand of a boy of approximately the same age, and possesses all the attributes missing in the type just described. The difference in the progress of these two pupils has been primarily determined by differences in the hand-formation.

Finally, in *h* is shown the tapering-finger type, popularly termed "artistic" (although it is usually the bane of the teacher); and in *i* a massive type. By looking at the hand types the probable differences in tone-production can readily be discerned. And, as a matter of fact, in these cases, the differences exist. Pupil *h* always plays with a light, delicate touch; pupil *i* characteristically forces the tone. Both have sufficient technical control and dexterity to eliminate these factors as determinants of tone-quality. Careful experimentation with both has convinced me that the difference is primarily the result of the anatomical structure of the hand, to which that of the arm should be added. This does not mean that the style is not subject to pedagogical control, but it does mean that the primary difference between the two is anatomical, having nothing to do with personality.

The tracings in Fig. 167 were used merely to illustrate differences in the anatomical structure of the hand as a whole. But similar differences, rather physiological in nature, exist in the articulations among the various parts of the hand. Sub-normal ranges of movement at any joint may be looked upon as a pianistic disadvantage. True, the player may overcome the limitation by substituting some other coördination for it, but the fact remains that this, in turn, becomes an unnecessary movement for the normal hand. Difficulties of technique may frequently be traced directly to a narrow range of movement in some joint or joints. Many hands, for example, with sufficient stretch to command an octave easily, cannot stretch C–E-flat–A-flat–C, right hand with 1–2–4–5 respectively because the angle of abduction between 4 and 5 is too small. They substitute 3 for 4, and thus find that a chord such as C–E-flat–G-flat–A-flat–C cannot be played. For other hands, stretches such as F–G-flat–A–C–F, C–D-flat–E-flat–G-flat–C, or A-flat–B–D-flat–E–B-flat played with 1–2–3–4–5, right hand, are not very difficult. They are impossible for many adult hands on account of the angle of abduction demanded between the fourth and the fifth fingers. I cite these examples merely to show

the direct dependence of some phases of technical ability upon the physiological structure of the hand. To convey some idea of the extent of these differences I measured the hand-movements of a number of pupils and in the following table give the extremes found.

	min.	maxim.	Range min.	Range maxim.
Dorsal flexion of wrist (bending wrist back) ..	45°	90°	100°	178°
Ventral flexion of wrist (bending wrist down) ..	50°	90°		
Wrist abduction toward 5th finger (bending wrist sidewise)	32°	62°	52°	93°
Wrist abduction toward thumb (bending wrist sidewise)	14°	35°		
Flexion of hand-knuckle, average for all four fingers	—	—	72°	90°
Abduction of extended fingers (sidewise motion), average for all four fingers	—	—	28°	40°
Flexion of middle-finger joint, average for all four fingers	—	—	90°	118°
Flexion of nail-joint, average for all four fingers	—	—	53°	86°

Significant as these individual differences are, they only begin to show the extent of physiological variations in piano-playing. If we recall the coördination demanded when the parts of the hand move near their extremes of range (see p. 45) we can understand the extent to which fatigue will play a rôle if the passage demands repeated use of this extreme range. A composition based upon full chords, even one of no great extent or difficulty, let us say the familiar Chopin Prelude in C Minor or MacDowell's "To the Sea", is extremely fatiguing to a hand whose angles of finger abduction (spread of fingers) can just about make the stretches. For a hand commanding a wider range, fatigue in these pieces is entirely absent. This fatigue is not the result of an incoördinated movement. It is the necessary accompaniment of motion at extreme ranges. Limitation at a single joint can cause it, if an awkward chord-position chances to recur sufficiently. And since the difficulty may not exist for the teacher's hand, the early onset of fatigue is often erroneously assigned to the stiffness of an incoördinated movement. I recall an instance where the change of a single finger, the substitution of 3 for 4 on A-flat in the chord C–E-flat–A-flat–C relieved the fatigue immediately and changed the playing of a piece from an awkward performance into a musically acceptable one. The chord occurred many times in the composition. Fine dynamic gradation, moreover, with the fingers in extreme stretches, is physiologically impossible.

It is usually very advisable for a teacher to acquaint himself with the details of the physiological structure of the pupil's hand. Pupils seldom use wrong fingering through sheer carelessness.

The fingering they substitute is, for them, an easier fingering, determined primarily by the physiological structure of the hand and the amount of training. A pupil with a very narrow hand and a wide stretch between thumb and second finger, frequently plays intervals as wide as a sixth, with 1 and 2, particularly if 5 be occupied. C–A-flat–C right hand, will be fingered 1–2–5 instead of 1–3–5, or better perhaps 1–4–5. The rapid playing of chords demanding wide spacing among 3–4–5 is a source of continued difficulty for such a hand. A pupil with a wide hand and a narrow or normal stretch between 1 and 2, will never finger the A-flat with the second finger. Short thumbs are another determinant. The passing-under in scales and arpeggios is doubly difficult and the smooth lateral shift of hand and arm are much harder to attain than in the case of normal or long thumbs.

Thus the ramifications of these differences extend over into the field of style. A knowledge of them will save the teacher much needless work on relaxation and phrasing as the pupil progresses. From the ranges given on p. 320, the probable later difficulties resulting from limitation of physiological movement may be learned at the beginning and appropriate measures of correction or adaptation taken.

When the differences in range of motion which we have just been studying reach extreme stages, they are customarily given specific names such as stiffness or double-jointedness. These terms do not designate conditions apart from all others, but merely those readily manifest on account of their magnitude. Similar conditions, as I have already mentioned, constantly exist in less degree, and often escape detection on account of their minuteness.

Stiffness.

In the chapter on The Skeleton, the tissues, cartilagenous and bony parts determining the amount of movement, were described. Here we are concerned with the effect of these restrictions upon hand- and finger-position and movement when applied to the keyboard. They are not infrequently found in the nail-joints of the fingers. As a result of this restriction, the playing-finger assumes the position shown in Fig. 168, in which the first interphalangeal joint (middle finger-joint) shows an excessive amount of flexion, in order to counteract the total absence of flexion at the nail-joint. The latter is not flexed because the restrictions at this joint make it impossible to flex it without a great amount of muscular contraction —and even then, in many cases, it cannot be done. But such an amount of contraction would make free finger-movement impossible

and, hence, would seriously interfere with actual playing. The fingers, when curved less than into a vertical position of the nail-joint have a tendency to extend (break-in) at the nail-joints, a thing which, again, is technically undesirable. Pupils with this articular limitation often lack the finer dynamic control upon which all piano tone-quality depends. This lack of control is caused by the "looseness" of the nail-joint when the middle finger-joint is fully, or almost fully, flexed. In such a position, when the finger is not resting upon any resistance, the finger-tip may be tapped and will spring back and forth, a movement over which there is no control. With moderate curvature at both finger-joints key-resistance can be accurately judged and an appropriate tonal intensity produced.

Another joint in which, as far as my own experience goes, limited motion occurs with sufficient frequency to warrant its discussion here, is the wrist-joint. The extreme range of motion at the middle finger-joint, of which only a small part is used in the finger-stroke of the pianist, and the motion at the hand-knuckles I have always found ample to meet all needs of a vertical finger-stroke. In the case of the wrist, however, limited extension or flexion is a drawback technically, because the wrist, far more than is generally supposed, is almost in constant use in any piano-playing beyond the elementary stage. In the table of hand-measurements, the range of dorsal flexion varies from 45 to 90 degrees. That is to say, some hands have twice the range of other hands. Above 75 degrees may be considered normal. Accordingly, a hand with a maximum wrist-extension of 45 degrees is handicapped in ease of movement. All hand-staccato, for example, demands wrist extension, and even the normal hand-position, as determined by the keyboard requirements (see Fig. 16*b*), demands a wrist extension of between 30 and 38 degrees. With a maximum range of 50 degrees, this requires constant playing near the upper extreme of range with its resultant physiological strain and fatigue. It is, therefore, quite natural that we find the pupils with this articular limitation playing from a "high-wrist" position, a position in which the playing-range has been thrown more nearly in the centre of the complete range of motion of the wrist-joint, which reaches over to the flexion-side as well as the extension-side. Such movement along the middle of the range of motion is physiologically easier than movement at either extreme, and is naturally adopted by the pupil. Coupled with this position of high-wrist is the fore-arm octave playing already described (p. 313) for small hands. In both cases the position of the wrist makes wrist-octaves awkward, thus favouring a transfer of the fulcrum to the elbow.

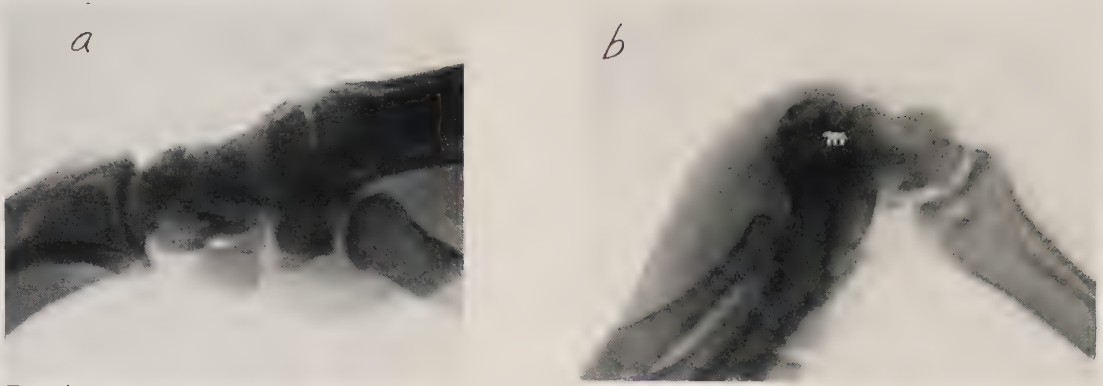

Fig. 169

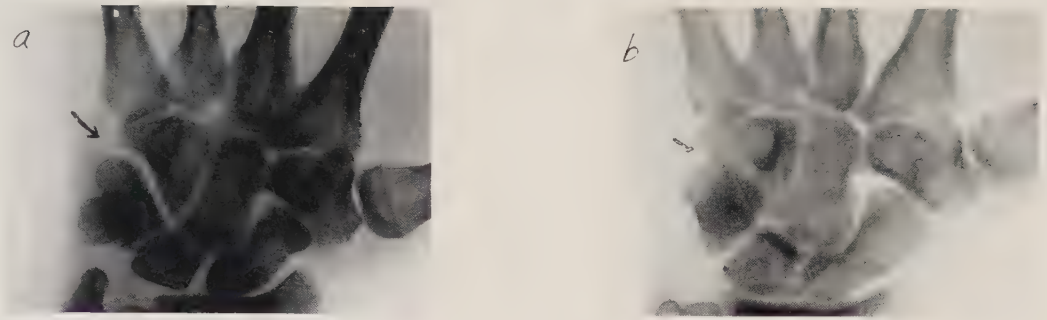

Fig. 170

Fig. 169 and Fig. 170. Bones of the wrist, showing differences in articulating surfaces.

[To face p. 322

Conditions of stiffness yield to treatment. Forceful pressing of the joint beyond the point of maximal flexion when only the muscles act, if done regularly and carefully, and if not forced too far or too suddenly, will gradually extend the range of motion, although the gain is small in comparison to the time, patience, and work expended thereon. The extent to which such treatment is successful, depends upon the exact nature of the stiffness. If the latter is in the capsular ligament, continued pulling will eventually add slightly to the length of this normally inextensible tissue. If in the cartilagenous part of the articulation, that, too, will yield slightly. If in the bone formation itself, little can be done.

It is unsafe to assign the restriction to ligaments or bones from external observation alone. The X-ray is necessary before the cause can be definitely located. Fig. 169*a* shows the left wrist region of a pupil who has a very limited range of wrist articulation. The carpal bones are somewhat thick, but, although contributing to the smallness of the range, are not of sufficient thickness to account for it entirely.

Fig. 169*b* shows a wrist in a position of extreme palmar flexion, the extreme pianistic high-wrist position. There is an unusual amount of movement between the metacarpal and the adjoining row of carpal bones at the point marked *m*. In the other figure the two sets of bones are shown in a straight line. (Compare also the wrist structures of Fig. 170 and note the differences in articulation between the two bones indicated by the arrow.) Conclusions drawn from one or two examples would be unsafe, but in all the illustrations given later we find such skeletal differences. As a matter of fact, Fig. 169*a* is the wrist of a pupil who cannot flex his wrist far, whereas Fig. 169*b* is a wrist with hyper-flexion, the same as that shown in Fig. 170*a*. An additional illustration, this time concerning the angle of flexion of the middle joint of the index finger, is given in Fig. 171*a*, *b*. In both cases the finger was flexed as far as possible, the pupils doing their utmost to bend the finger at that joint. In *a* the bone-ends are not in contact on the ventral surface, indicated by the arrow. Consequently, the impossibility of bending the finger further at this joint cannot result from skeletal limitation, but must result from the contact of the fleshy parts, tendons, and ligaments. In *b*, however, the edge of the one bone (second phalangeal) rests flush against the inner side of the first phalangeal, thus setting a definite bone limit to the range of movement. Fig. 171 shows the impossibility of assigning range limitation to a single factor. Two factors may operate: the bones, and

the soft parts surrounding the joints. The illustrations in Fig. 171 are interesting because case *a* has considerable difficulty in technique on account of the very limited range of movement in the various joints, whereas *b* is the finger of a pupil with marked technical ability.

Double-Jointedness.

The opposite of the subnormal articulation just described is the excessive range of articulation shown in cases where the well-rounded form of the bone-ends and the receded position of cartilage or the relative looseness of the capsular ligaments permit a greater motion in the joint than that normally found. This condition I have found of more frequent occurrence than the condition of equally marked subnormal articulation, and the difficulties which it presents to pupil and teacher are also more numerous.

The use of the word double-jointedness is unfortunate. The articulation is not double ; that is to say there are not two joints present for the normal one. The difference is merely one of degree, the formation of the bones at the joint in addition to the stretch of capsular ligaments and tendons permitting the bones to move further over the articulating surfaces than normally. The jerk which is a familar " stunt " of people possessing such joints results from the sudden slipping of the articulation from one plane to another. Such a jerk is usually most noticeable with considerable simultaneous contraction of flexors and extensors. This, as I pointed out in the chapter on Relaxation, presses the surfaces of the joint more firmly together. Consequently, there is more of a snap when the plane of articulation changes abruptly.

The condition may occur in any joint, series of joints, or in all joints of the hand. One extreme case has come to my attention where the snapping noises, as a result of double-jointedness in the large as well as the small joints throughout the body, made it quite impossible for a young lady to enter church or the quiet of a theatre without attracting attention from all sides.

The joints most frequently involved in hyper-movement in piano-playing, perhaps, are the middle thumb-joint (thumb-knuckle) and the hand-knuckle of the fifth finger. When the former breaks, it seriously interferes with the stretch between thumb-tip and little finger, reducing it often to a point at which octave-playing is impossible. Next in order of frequency are the metacarpo-phalangeal joints (hand-knuckles). An extreme instance of the latter with hyper-extension of the wrist, permits the pupil to touch the back of the fore-arm with the finger nails of the fingers on the same arm,

Fig. 171. *a*, Flexion of first interphalangeal joint stopped by flesh and tissues; *b*, same joint stopped by bone contact.

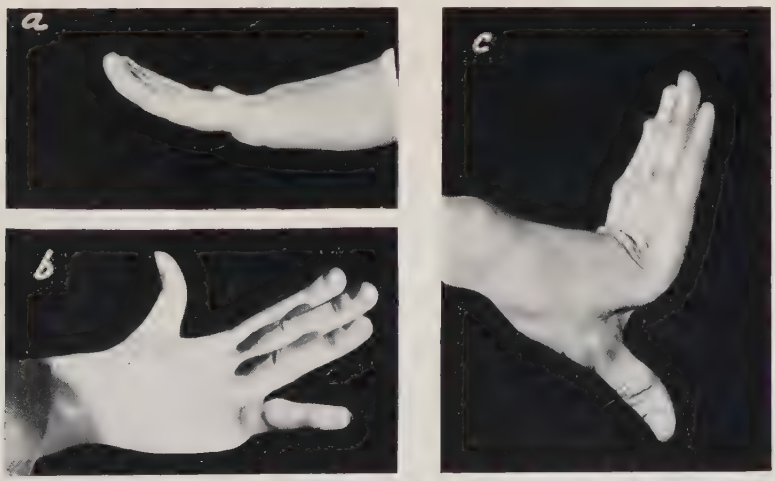

Fig. 172. Various types of hyper-extension ("double-jointedness").

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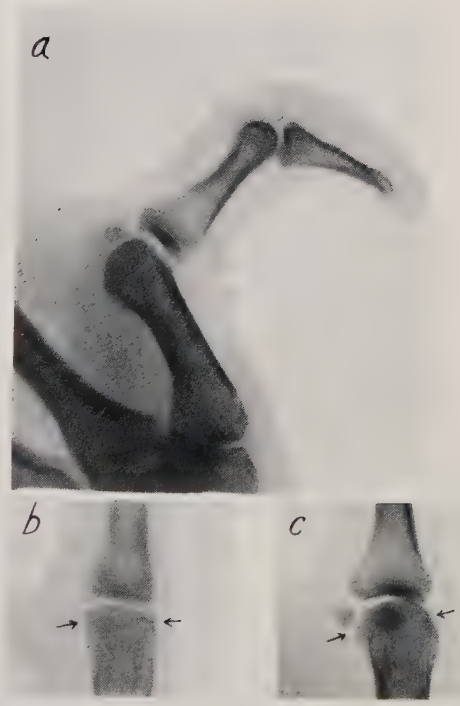

Fig. 173. *a*, Hyper-extension in thumb-joints; *b* and *c*, differences in bone-ends responsible for differences in range of movement.

Fig. 174. 90° hyper-extension in the hand-knuckle of the fifth finger.

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by pushing back the fingers at the metacarpo-phalangeal joints. Recently I have met with a case of marked hyper-extension in the middle finger-joints as a result of which the hand frequently assumes the position such as that in Fig. 172*a*. *b*, in the same figure shows the double-jointed fifth finger, and *c* shows marked hyper-extension in all hand-knuckles, the last against external resistance.

As with stiffness, so with looseness: it may be caused either by bone-formation or loose ligaments surrounding the joints, or both. The X-ray will definitely reveal the former, and the absence of bone-cause makes the ligamentous inference safe. Fig. 173*a* shows a case of a double-jointed thumb. In both joints, particularly in the knuckle, the one bone has slipped completely around to the side of the other. Moreover, there is still a noticeable gap between the head of the metacarpal and the base of the first phalangeal. Fig. 173*c* shows the same joint, and, for comparison, *b*, another thumb-joint of a pupil who has difficulty in flexing the thumb in either direction. Here a very marked difference of bone structure may be seen. In *c* the head of the metacarpal bone is entirely round, in *b* it is flat. The arrows point to the differences in curvature. It is obvious that the turning of the upper bone upon the lower can take place through a much greater range and much more smoothly in *c* than in *b*. Here, then, is a definite skeletal difference. No amount of practice and no stretch exercise will help *b* to increase the range of action to that of *c*. It so happens that the pupil with limited range shows similar structure in other joints. At the same time he has extreme difficulty in technical passages, which he cannot overcome in spite of a great willingness to drill.

In Fig. 174 an extreme case of double-jointedness in the hand-knuckle of the fifth finger is shown, and also in the nail-joint. The direction of the bones at the bottom of the picture points out the position of the hand, which is horizontal, so that the fifth finger stands vertically. The first phalanx has moved entirely on top of the head of the metacarpal bone. The position is that given in Fig. 172*c*.

But, although the differences just mentioned are entirely skeletal, it is not safe to attribute all instances of double-jointedness or stiffness to bone-structure.

Fig. 175*a* illustrates the hand-knuckles, seen from above, of a pupil whose range of flexion at these joints is very limited. But the formation of the bone-heads and bases, as well as the distances between head and base are very similar to, almost identical with those of a double-jointed hand *b*, the same figure. Yet the differences in facility of movement between these two hands, as measured

by finger-movements, especially in the joints photographed, are most marked. In such cases, the limitation must be caused by the ligaments and flesh surrounding the joints. In Fig. 176 the nail-joint of the index finger of a violin pupil is shown. The pupil has difficulty in getting this finger-tip on the finger-board in a flexed position. In this case the difficulty seems to be both skeletal and ligamentous. The joint shows a very close articulation between the two bones, the middle finger-joint showing a more rounded spacing (compare also with articulation in the similar joint of Fig. 171*b*). In the second place, the base of the third phalanx is rather pointed and meets the head of the second phalanx at its ventral edge, thus, perhaps, preventing the bone of the finger-tip from sliding around the side easily. Such a bone-position can be caused by the restriction of the dorsal capsular ligament. If the bones were a bit looser and the extensor tendon and capsular ligament also, the bone formation alone would not limit the range at the point given.

Nor do all cases of hyper-movement result from bone-formation. In both *a* and *b* of Fig. 177 the bone-ends, base and head, are relatively flat (one shows the thumb-tip, the other the fifth finger-tip), yet in both cases full extension was possible. This is again a ligamentous difference, operating this time by being too loose, whereas in Fig. 176 it limits the range by being too tight.

Hand-Types.

Individual differences in hand-movements, however, are not restricted to the joints, nor to the formation of the heads and bases of the bones. Differences in the bone-shafts likewise affect the manipulation of the hand parts. I shall take up next the study of a few hands of pupils with whose work I am very familiar, and shall attempt to point out some physiological causes of their various technical abilities.

Fig. 178 shows the skeleton of the left hand of a male adult. The individual characteristics of this hand are :—

(1) General heavy bone structure.
(2) Width of bone-shafts compared with heads and bases.
(3) Close approximation between the first and second phalanges.
(4) Heavy, but not particularly closely articulating, carpals.

The technique of this pupil is extremely limited. His hand, in playing, falls naturally into two positions : when the arch is maintained, curving of either finger-joint is lost. When curved finger-tips are demanded, the hand-arch breaks. A study of

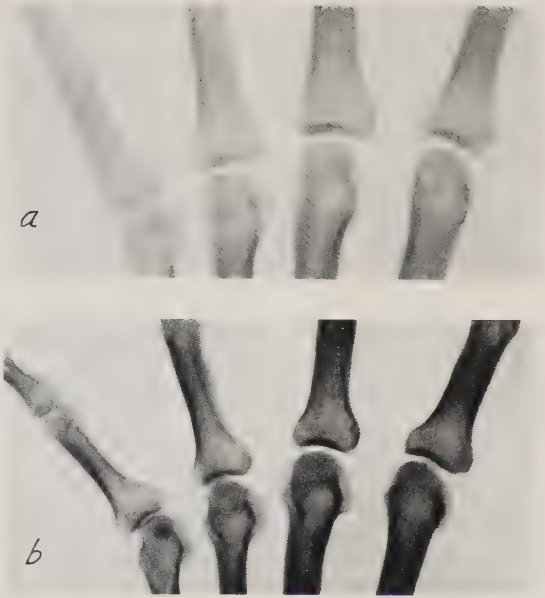

Fig. 175. The hand-knuckles (metacarpo-phalangeal joints).

Fig. 176. Hypo-flexion in nail-joint of index finger.

Fig. 177. Full extension with non-rounded bone-ends.

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Fig. 178. Differences in articulation between hand-knuckles and finger-joints.

Fig. 180. Lateral view of hand-knuckle.

Fig. 178 shows that greatest ease of movement is in the hand-knuckles, the bone-ends here being less close than in either first or second finger-joints. If the close approximation in the finger-joint makes flexion in these joints more difficult, and mechanically this is not only possible but necessary, a cause for the hand assuming either of the two positions is shown. As a matter of fact, intensive drilling to alter this condition has produced scarcely any results, which strengthens the assumption that the hand-position difficulties are the result of skeletal structure. His octave technique, so far as the freedom of movement is concerned within a limited range, is normal, and the wrist region of Fig. 178 shows a normal bone-structure.

Fig. 179 is the right hand, palmar view, of a male adult. The characteristics to be noted are :—

(1) Massive bone structure.

(2) Cylindrical shafts of most bones (compare with Fig. 181 and Fig. 183).

(3) Relatively flat heads of the metacarpals (*m*).

(4) Parallel edges between the bases of the first phalanges and the heads of the metacarpals (*m-n*) (compare with Fig. 181).

The technique of this pupil is characterized by an unusually stiff hand, with very limited movement in the hand-knuckles, both in a vertical plane (flexion and extension), and in a horizontal plane (abduction). Difficulty of thumb-action is also present. A study of Fig. 179 shows that the massive bone-structure, particularly in the metacarpal region, restricts the spaces in which the interroseous muscles and the lumbricales are situated. This position may be seen by referring to Fig. 18 E showing the muscles of the hand in position. Apart from the strong skeletal structure, the pupil has strong hand muscles. Since the power of a muscle depends upon the size of its cross-section, the muscles, like the bones, are thicker than usual. Accordingly, they press more firmly than usual against the sides of the bones themselves and upon the surrounding tissues. Moreover, in watching the finger-movements, and by trying the experiment (described on p. 117) of pushing aside the tendon, I found that the tendons themselves were not slack, even in a state of complete relaxation. These conditions combine to produce what we generally term a tightly-knit hand, a condition to which the thick fleshy parts, shown in faint outline in Fig. 179, contribute. Were the metacarpal bones less cylindrical, the interroseous muscles, lying parallel to the bones and between them, would leave more room for the tendons, circulatory vessels, and nerves that pass among them.

The flat heads of the metacarpals, seen from above, do not themselves affect the down-stroke of the finger, unless the same bone-formation is present when viewed from the side. This is not the case. In Fig. 180 which is another picture of the same hand, the round head of the metacarpal and those of the first phalanges can be seen. Accordingly, any restriction of vertical movement at these joints is not caused by skeletal structure. This does not hold, however, for lateral movement: the spread of the fingers. Here the flat heads prevent the head from acting as a centre of the arc of movement. The actual centre for the fourth finger is at *o*, Fig. 179, beyond the head, along the shaft, six-tenths of an inch from the articulating edge. In Fig. 181 a normal bone-end is shown and the centre of abduction is again indicated by *o*. The point now lies in the head of the bone one-quarter inch behind the articulating surface. The lengths of the two hands in question are, respectively, eight, and seven and one-half inches, so that the difference in the arcs of movement are not the result of mere hand-size. In the case of the flat-head, the phalanx must shift sidewise considerably before being able to turn. In the normal case the turning begins immediately without any lateral shift. And since a lateral shift at these joints is normally impossible on account of ligaments and hand structure, the difficulty of finger-spread in a hand with relatively flat metacarpal heads, is readily understood. In such a case no amount of training will help, a fact demonstrated by several years of practice in this particular case.

Fig. 181 is a Roentgenogram of the hands of a very talented girl of fifteen. The left hand is a dorsal view, the right hand a palmar view. The type of hand, as the outlines indicate, is the long, slender type. Articulations in all the joints are free: the shafts of the metacarpals are slender, allowing ample room for tendons and muscles. The formation of the nail-joint of the thumb prevents hyper-extension at this joint. For the sake of comparison I add a case of the opposite condition, in which the pupil can bend back the thumb-tip considerably at the nail-joint, Fig. 182. It is a very noticeable example of range being determined by bone-formation. In Fig. 182, showing the nail-joint of the right thumb, the edge *b* protrudes beyond *a*; in Fig. 181 for the same joint the reverse is the case.

Fig. 181 may be considered a typically favourable skeletal structure for the particular type of hand shown. The dark lines running across the head of the radius, at the bottom of the picture, are not fractures, but lines of ossification, the head uniting firmly with the shaft at about the twentieth year. (No wonder the

Fig. 181. Typical normal skeletal hand-structure. Narrow hand, long fingers.

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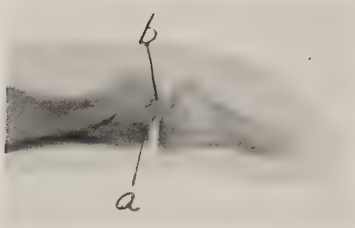

Fig. 182. Limitation of range by bone formation.

Fig. 183. Limitation of abduction between third and fourth fingers by tissues. Skeletal structure would permit greater range.

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specialist smiles when his female patients give a fictitious age. He may put down quite a different age when he sees his X-rays.)

We have thus far considered limitations in range when they were abnormal. In normal hands the limitations are almost always caused by tendonous pull, skin or other ligamentous structures. In Fig. 183 maximal abduction between the third and fourth fingers is shown. The hand is the same as that of Fig. 181. In this case the limitation is obviously caused by the skin and the ligamentous sheath that runs across the hand in the region of the hand-knuckles. The joints are by no means at their limit of range, being scarcely affected by the spread. Accordingly, in such instances, properly conducted massage of the skin region between the fingers will help to increase the range of movement when this is desirable, for all living tissue yields to prolonged tension. As we have seen, in all narrow hands, considerable finger-spread is needed to make up the deficiency in hand-width (see Fig. 164). Were the limitation skeletal, such exercises would have little or no value. Obviously, when either hyper- or hypo-tension occurs in many joints, the effects are summated and the pedagogical difficulties are correspondingly increased.

Whatever be the location or form of double-jointedness, the effect upon the mechanical principle underlying joint-movement (stationary fulcrum) is the same. The resistance which the normal joint interposes against excessive motion in any direction is missing. Accordingly, if motion in that direction beyond the normal limit is to be restricted, this work must be done by those muscles pulling the bone in the opposite direction ; in the cases here described, by the flexors of the various joints. In other words, whatever excessive " looseness " or " play " exists in the joint must be overcome by contracting the muscles ; a contraction that will most often involve both flexors and extensors, so as to press the articulating surfaces more firmly together or to take up any " slack " in the surrounding tissues. Needless to say, this will not actually reduce the range of motion, but will minimize the danger of the bone ends slipping into the extreme position under normal resistance. A physiological reduction of the range of motion into the normal I do not consider possible. But a control of the range of motion is entirely possible with proper muscular contraction. Muscularly the problem is similar to the breaking-in of the nail-joint, and its correction is correspondingly the same. Moreover, any exercises that develop the flexors without at the same time (through return motion) developing the extensors, are useful devices, since they will turn the balance of muscular pull toward the palmar side of the hand,

where it is wanted. Squeezing an elastic body small enough to be held in the partly closed hand, with all fingers, letting the elasticity of the body re-extend the fingers, is such an exercise. By its constant use I have succeeded in overcoming in two years many pianistic defects of a markedly double-jointed hand.

Fig. 184 illustrates the physiological and mechanical causes for joint-action in the condition called double-jointedness.

The preceding X-ray photographs of such fingers, give the actual picture of the skeletal position. Fig. 184 is a diagrammatic representation of the interaction of the forces at work. The finger-position shown is taken from an X-ray for a double-jointed fifth

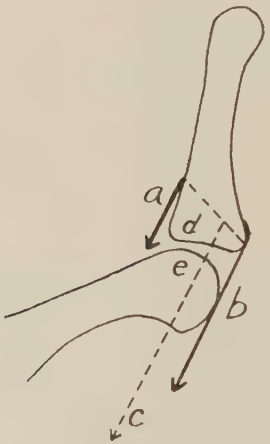

Fig. 184.

finger, and the joint represented is the hand-knuckle of that finger. *a* represents the line of pull of the finger-extensor, *b* that of the finger-flexor, which is assumed to be pulling twice as hard as *a* and should normally pull the bone end *d* around toward the lower side. We find, however, that, in the position given, both forces are acting parallel. Their combined action, therefore, according to the principle under Parallel Forces in the chapter on Mechanical Principles, is a resultant of the magnitude and direction of the dotted line *c*. Such a force will not only pull *d* firmly against *e*, but will even pull *d* in the direction of *a*, instead of *b*, thus causing *d* to slide still further over *e*. Before this can be overcome *a* must relax. But the hyper-extension is the result of the action of *a*. Consequently, the position shown is flatly opposed to finger-descent.

In order for this to take place, a pre-relaxation of *a* is necessary. Not only that, but *d*, on account of the rounded head of *e*, may slide around its upper side, thus making any finger-descent impossible through the contraction of *b*. Double-jointed pupils are well aware of this inability to move the finger until the "kink" is released. In the position of Fig. 184 force *a* is acting at an advantage, *b* at a decided disadvantage. For finger-stroke the conditions should be reversed. (See Fig. 103, showing angles of pull.)

Since excessive range of motion is the result of a certain amount of "play" in the joint, adequate contraction of the muscles controlling motion at this joint will help to overcome the "looseness". By adopting, as normal, a hand-position requiring a degree of muscular contraction that makes hyper-extension at the joint impossible, the tendency to fall into the double-jointed position can be guarded against effectively. This does not, of course, change the bone or cartilagenous formations at the joint, but merely holds the joint in normal position by appropriate muscular contraction. For this reason it is decidedly inadvisable ever to carry the joint in the undesirable position. Balling the hand into a fist, firmly; playing full chords *fortissimo* with firm arch; and all firm grasping of round objects are effective means of forcing the arched hand-position and making hyper-extension improbable. To these may be added the familiar table exercise in which the hand is drawn from a flat position into an arched position by gradual contraction of the flexor muscles. This should be accompanied by reasonably firm pressure upon the table. In all these exercises, however, we do not alter the physiological cause of the double-jointedness, but, by developing the flexor muscles we make a moderately flexed position of the hand seem more natural than before. The basic difference remains the same: in the normal hand the resistance near the extremes of range is interposed in a natural way by bone-formation, or inelasticity of tissue, or both; in the loosely-jointed hand, this resistance must be interposed by muscular contraction.

The joint which most frequently shows excessive range of motion is the second thumb-joint, the thumb-knuckle. The condition is sometimes restricted to this joint alone, although it is likewise not infrequently associated with the double-jointedness in the hand-knuckles of the other fingers, just described. In the case of the thumb it is even more annoying, for although the extreme extension of the fingers plays no real part in piano technique, the extension of the thumb is necessary in all octave and over-octave stretches. As a matter of fact it is necessary, in small hands, for stretches

less than an octave. As in the case of the fingers, forced flexion is the best means of overcoming this hyper-extension. Any flexion of the nail-joint facilitates flexion of the middle-joint because the same set of muscles is involved and the tendon of the nail-joint passes under the middle-joint as well. Accordingly, by holding the tip of the thumb well bent-in (flexed) we indirectly make the breaking-in at the next joint more difficult. The correctness of this procedure is illustrated by the position assumed by the thumb if the tendon controlling flexion of the nail-joint is severed. When this happens, the opposition to the breaking-in of the middle-joint is removed, and the break occurs more readily and with correspondingly greater persistency. This I observed, particularly, in a case in which a deep cut had severed the flexor tendon and a foolish piece of surgery failed to permit it to knit. The tendency of the middle-joint to break-in after the wound had healed was double; in fact the joint was habitually carried in this hyper-extended position (a modified form of Fig. 177*a*). The physiological cause is found in the *extensor pollicis*, which extends the nail-joint of the thumb and then, by passing over the middle-joint tends to extend that also, and will extend it, even in normal conditions. Being unopposed by the flexor, this muscle naturally forces the joint to break. It is for this reason that the opposite contraction, maximal flexion of the nail-joint, is useful in correcting the break-in at the neighbouring joint. The particular case cited is concrete evidence of tendonous pull as a determinant of joint range.

The double-jointedness of the fifth finger at the hand-knuckle may be corrected by substituting a straight finger-position for the curved one. In the chapter on Finger-Stroke the details of finger-position are analysed and the difference in lift between an extended and a curved finger is illustrated. Reference to Fig. 184 (double-jointed) shows that once beyond the straight-line position, the tendency of additional contraction of the extensor to cause the bones to " slide ", is marked. The line showing the muscular pull illustrates this. By keeping the finger extended, we can gain sufficient lift at the finger-tip for the desired tone-production without exceeding or perhaps even reaching the straight-line position at the hand-knuckle. Frequent reference has been made to skeletal position, the position taken so that the bones form a relatively straight line directed against the action of the piano-key. One instance is the flat and the curved finger-position. In Fig. 185*a* the nail-joint of the index finger is not flexed at all. The position of the bones in this finger shows that when the key is reached and the force acts vertically upward it will act at a maximum angle

Fig. 185. *a*, *b*, *c*. Differences of skeletal resistance in various pianistic finger-positions.

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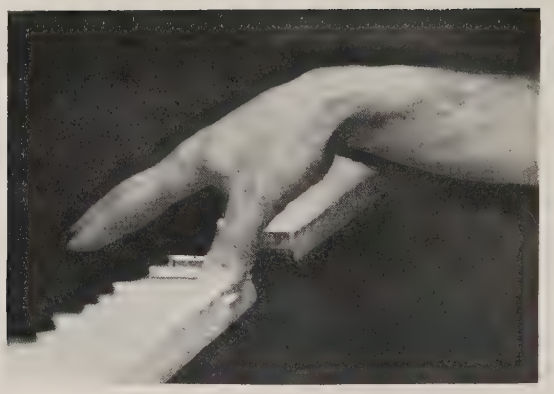

Fig. 186

Fig. 187

Figs. 186 and 187, *b*. Skeletal hand-positions, with phalanges and metacarpals in approximately straight lines.

Fig. 187, *a*. Muscular hand-position, with flexors of fifth finger resisting the pressure at fifth-finger tip.

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of efficiency, whereas the finger-flexor, the tendon of which parallels the bone, is acting at a very poor angle. The key-resistance, therefore, will have a tendency to bend back the nail-joint. In *c* of the same figure, where the arched hand-position with curved finger is shown, the bone in the nail-joint is vertical and the adjoining bone almost so. As a result, when key-resistance acts vertically upward, the bone-ends will be pushed together, thus relieving the muscles of a part of their contraction. The bone-position shows that merely curving the fingers may be sufficient to secure the firm nail-joint required in piano-playing, but not necessarily.

Similar observations apply to the hand-knuckles. In the flat hand with over-extended finger, Fig. 185*b*, the skeletal assistance cannot be present, because the first phalanx is above the horizontal and the force-action of key-resistance is vertical. In the arched position, between metacarpal and first phalanx, the angle is less and the phalanx is lower, thus interposing to a modified extent, the resistance of the metacarpal bone, besides letting the flexor act more efficiently.

Note that in the case of the thumb we have no such skeletal considerations. This digit plays on its side, hence interposes a fairly rigid bone structure throughout its length. The only joint at which vertical movement can freely take place is the joint near the wrist. In the positions shown at *a* and *c*, a vertical upward force at the thumb-tip places a marked strain on the muscles controlling the joint near the wrist, on account of the leverage position. As the wrist is raised, the bone position changes to that shown at *b*, resting the end of the metacarpal bone of the thumb more directly against the carpal bones of the hand. These, then, take care of part of the force of key-action. The raising of the wrist, accordingly, in pupils with weak hands, or even in adults, when excessive tonal intensity is wanted, is the natural substitution of skeletal position for muscular. A photograph of such a position, with the hand ready to play *fortissimo* octaves is shown in Fig. 186. For the sake of comparison the muscular position for octaves, Fig. 187*a*, is added. Here, as the position of the fifth finger shows, the key-resistance is opposed by the muscles of the fifth finger. *b* in the same figure shows the fifth finger when the position in Fig. 186 is used. This finger does not even touch the key, the one tone of the octave then being played with both fourth and third fingers. In this position there is little danger of tearing a tendon in *fortissimo* work, a result that can readily occur if position *a* be used.

Hand-Type and Style.

It is quite natural, even necessary, that such differences as those which we have just been considering should affect the style of the player. Elsewhere I have mentioned the fact that pupils seldom adopt wrong fingering merely by chance. Their choice is determined by the greater ease, for them, of the fingering used. And this ease varies with the physiological structure of the hand. A few examples, taken at random from my own observations may serve as illustrations. The pupil whose hand is shown at *a*, Fig. 167, always plays with the third, fourth, and fifth fingers bunched, that is to say, without spread in these fingers. The excessive stretch between the thumb and the first finger plus the size of the hand make the playing of octaves with the first and third fingers, or even first and second, quite possible. And the pupil plays octaves, with the fourth and fifth, on a single key, or at times even with the third and fourth on a single key. It is an extreme case of the second physiological subdivision of the hand: thumb, index, and 3–4–5 (see D, Fig. 165). And for the same reason, any pianistic figure requiring abduction of these three fingers is unusually difficult for this pupil.

The hand shown at *f*, Fig. 167, with the short thumb and short fifth finger, seldom employs either, if it can possibly be avoided. A left hand waltz accompaniment, for example, in which the low bass notes and one of the chord tones are usually played with the fifth finger and the thumb respectively, are, in this case, repeatedly played with the long fingers, especially the third; first and fifth are not used at all unless the number of tones present forces their use. Here we have a division into three hand parts, the thumb facility and that of the fifth finger being insufficient to cause these digits to be used with normal freedom and frequency. Such a thumb difficulty, of course, becomes especially noticeable in scales and arpeggios.

As an opposite case we may take the hand shown in Fig. 167*e*. This pupil has no such difficulties. Spacing of chords, thumb-action, spreading of 3, 4, 5 yield readily to treatment. The hand at *i*, Fig. 167, has no difficulty in normal spacing on account of its width, but the shortness of the thumb and the unusual thickness of the thenar eminence make scale work, and especially arpeggio work, very difficult.

Take again the case of a narrow hand. For such a hand, chord spacing demands wide abduction of the fingers (see Fig. 164). And such abduction is opposed to finger-flexion on account of the physiological structure of the hand. Accordingly, pieces such as the

PLATE XLV

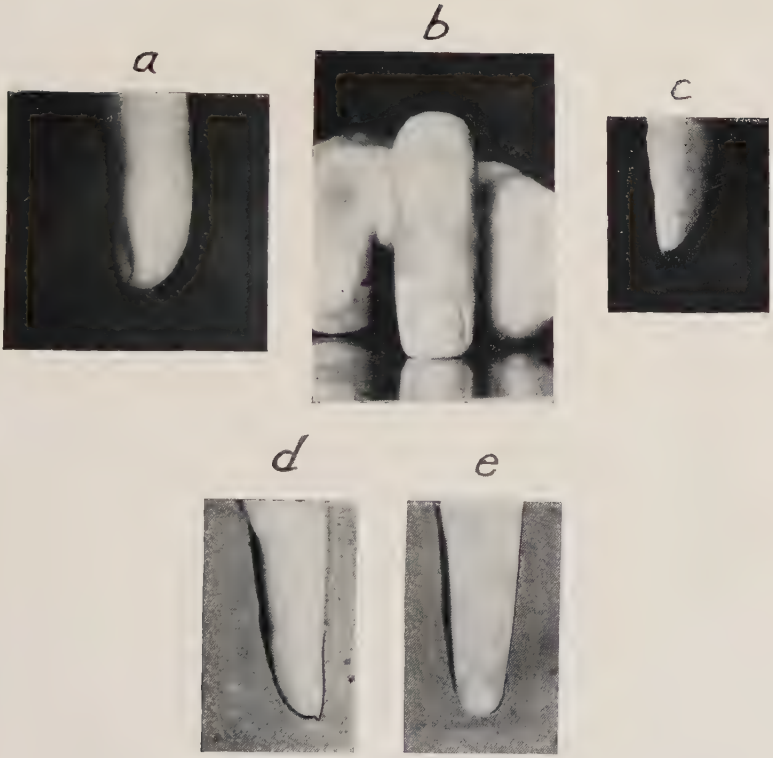

Fig. 188. Anatomical differences in finger tips, showing various degrees of "cushioning."

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Butterfly Etude of Chopin, Op. 25, No. 9, fatigue the hand very quickly because both spread and very rapid and oft repeated finger-flexion are necessary. A wide hand, playing with less abducted fingers, fatigues much less quickly. Moreover, the additional finger spread which the narrow hand requires places an additional strain upon the wrist, for we have seen that finger abduction and finger extension are associated. Should there be any pathological sensitiveness in the wrist region to cystic formation, the condition will be aggravated by such stretching. I am at present working with a case in which the size and annoyance of a cyst can be definitely controlled by certain technical assignments.

For such hands the question of appropriate fingering is of great importance. Any fingering requiring abduction of the fingers should be avoided when possible. The same rule applies to small hands. The introductory measures of Beethoven's C-sharp Minor Sonata, Op. 27, already mentioned, should thus be fingered 1–3–5 instead of 2–4–5 by such hands.

Finger-Tip.

The actual organ of tone-production on the piano is the finger-tip, and the physiological differences in the size and formation of the hand involve the finger-tip as well. Two factors are of practical importance: the amount of cushion beneath the nail, and the projection of the nail beyond the end of the finger. Fig. 188*a* shows the side view of a well-rounded finger-tip; Fig. 188 *c* and *d* a similar view of a tapering finger. The former could be much compressed before the flat head of the bone-end makes the striking finger surface hard. The tapering finger will stand less pressure, for there is too little flesh between skin and bone. The impact noises of the two, when a percussive attack is used, will differ somewhat, being more marked for the tapering finger.

This difference, however, is of less practical importance than the position of the nail itself. In *c* of Fig. 188, although the nail is cut short, it still protrudes beyond the flesh. And in *d* and *e* of Fig. 188 no cutting of the nail, as I happen to know from experience, can prevent this protrusion. Compare with this *b*, of Fig. 188. Here the nail is not cut too short, and great pressure is forcing the vertical nail-joint against the hard surface. Yet the nail does not come into actual contact with this surface, as the reflection beneath shows. Accordingly, the finger positions adopted by the two types of finger-ends should differ, for it is never advisable to let the finger-nail strike the piano-key. The vertical nail-joint is impossible for the tapering finger.

But since finger-position is one determinant of tone-quality (see Chapter XVII), this physiological difference will affect the tone-production itself. The pupil with tapering fingers will normally play more softly. Moreover, since in the extended finger the contraction of the finger-flexor differs from that used with a vertical nail-joint (see Fig. 105), the two types of finger require different muscular coördinations, and these affect not only the finger, but the hand and the arm as well.

Hyper-extension, too, has its effect upon style. Since the fulcrum for the finger-stroke is at the hand-knuckle, and it is this joint at which the excess motion occurs, accurate control becomes more difficult, and we find pupils with this excess range playing in a light, often unclear manner, or else, when fixation is attempted, resorting to excess fixation (really necessary on account of the normal excess extension) and forcing the tones beyond the desired intensity. The lightness of tone also results from the excess finger-lift which the fingers naturally adopt. In such cases it is doubly necessary to develop finger strength so as to minimize the finger-lift, and to direct attention to the down-stroke only.

CHAPTER XXIII

Tone-Qualities

After all, the chief reason for varying the standard touch-forms which we have been considering, is the production of the desired tone-quality. And in this quality business lies the cause of the countless polemic articles, pro and con, about the effect of touch upon tone. It is now definitely known through both theory and experiment that all qualitative differences, excepting the variations in the noise-element, are quantitative differences. Tetzel, the leader in Germany in the defence of this principle, has pointed out the intensity determinant a number of years ago, and sums it up in a law of dynamic or intensity relativity, as a result of which variations in or the relationship among the intensities of the tones is the fundamental determinant. This is true, if we add variations in the noise-element.

In attempting to record tonal-qualities produced by players who affirm that they are not quantitative variations, we are faced with several difficulties. If the key-action is connected with a recording apparatus registering force-variations—and upon these the qualities depend—we necessarily change the normal key-resistance and thus deprive the player of the mechanism by which the tone is produced. If, on the other hand, we merely introduce the resistance at the bottom of key-depression, we shall fail to get the necessary variation, for tone is produced before the key is fully depressed. The apparatus used in most of the following experiments does not entirely overcome these difficulties, but by securing records in sufficient quantity, and by various other means such as the dynamograph, apart from the keyboard, as well as by learning from the introspection of the players themselves whether they felt that the tonal result had the desired quality, we can get an array of evidence that warrants definite conclusions. Then, too, we have the theoretical analysis, with which the experimental results have to agree.

The apparatus used consisted of a series of steel springs, one attached to the inner arm of each key-lever through a range of several octaves of the keyboard. This permitted playing the keys as usual without destroying the tone. The resistance of the springs

was adjustable so that a very slight increase over normal key-resistance could be used as well as a resistance sufficient to withstand the force of *fortissimo* work. To the keys themselves the aluminium recording levers already described (Fig. 110) were attached, communicating the key-movement in a magnified form to the smoked surface of a revolving drum. The adjustable spring resistance could vary so that pressure up to full depression was recorded. The magnification by the recording lever took care of very slight fluctuations in key-movement.

If tone-qualities depend upon force-variations, then we should get a distinct form of curve for each quality. Vertical displacement in the following figures means an increase in intensity, horizontal displacement means the duration of the stroke or of the pressure. In interpreting the curves we shall be obliged to touch upon certain psychological phases, in order to explain the connection between the type of curve and the tone-quality. It is quite possible that several of the terms, as applied to tones, may not convey a clear meaning to each reader. In order to reduce this ambiguity to a minimum, I have selected only those frequently used by both pianist and auditor. Many others, in addition to those here given, were recorded, but in no case did the resulting curve conflict with the conclusions drawn from the records in this chapter.

To avoid needless repetition on the description of each quality, the following legend is given. It applies to all figures in this chapter recording tone-qualities.

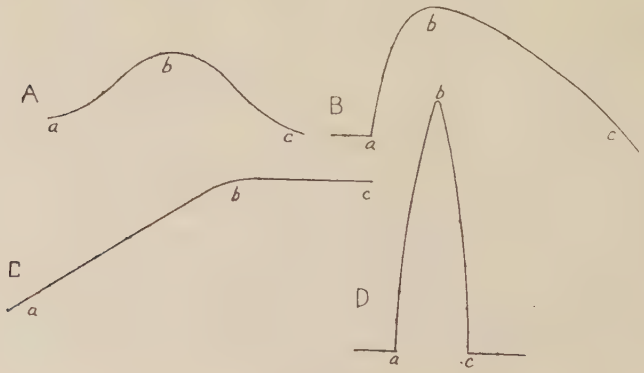


Fig. 189.

A, gradual varying increase in pressure as key is depressed (*a* to *b*) ; gradual release of pressure as key ascends (*b* to *c*) ; weak intensity.

B, the sharp angle at the beginning denotes a percussive touch, with sudden application of force (*a* to *b*) ; gradual release of pressure (*b* to *c*) ; moderate intensity.

C, constant increase in pressure, relative slow key-speed (*a* to *b*) ; maintenance of pressure (*b* to *c*). Intensity same as B.

D, percussive touch, great intensity (height of *b*) ; extremely short duration (*a* to *c*).

The time-line in all the figures records fiftieth of seconds. All figures are to be read from left to right.

Sparkling.

The curve for this quality is given in Fig. 190. Its characteristics are percussiveness, shown by the abrupt initial rise ; moderate to great intensity, shown in the amplitude or height of the curve ;

Fig. 190.

and extreme brevity in duration, shown by the small horizontal displacement. The word " sparkling " is borrowed from the visual field in which it denotes a light of relative'y great brilliance,

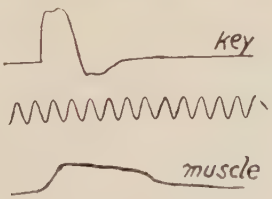


Fig. 191.

little expanse, and short duration. These qualities are then transferred to the auditory field necessitating the tone-production just described, high pitch taking care of the visual expanse. The Etincelles (Sparks) of Moszkowski is a musical illustration of this tone-quality.

The muscular contraction producing such a tone-quality is, as we should expect, a rapid initial contraction of relatively short duration. It is illustrated in Fig. 191 in which the key-line (reversed) is recorded only slightly magnified and showing the full key-depression, so that the time-relationship between muscular contraction and the resting of the key upon its key-bed may be studied.

The muscular relaxation takes place noticeably more slowly than key-release. This probably results from the fact that in the quick release of the hand from the key, the same muscles that brought about hand-descent act to prevent over-extension of the wrist in quick hand-ascent. As a result the relaxation is only partial, keeping hand-ascent under control.

Velvety.

A curve for this quality is given in Fig. 192. Its characteristics are : a gradual increase in pressure, beginning with a non-percussive attack ; long duration, moderate or little intensity and gradual

Fig. 192.

release of pressure. When this quality is applied to a series of rapid tones, the gradual increase and release of pressure are absent, but the moderation of intensity and non-percussive attack remain. Moreover, when these attributes were altered, it was impossible to produce the desired tone-quality. The similarity of this touch-form to the touch-sensations of softness and smoothness produced by the texture of velvet is obvious. Of course, none of the graduality of increase or release of pressure goes into the tone itself, and the lack of percussiveness does not mean a non-percussive attack of the string. Such assumptions are artistic illusions. Lack of percussiveness reduces the noise-element and thus permits a purer tone to be heard, but it does not affect the tone itself. From a purely tonal standpoint a velvety tone is one of weak to moderate intensity and relatively long duration. In a sequence of tones this length of duration is replaced by equal intensities of the constituent tones and a high degree of legato. Short, detached tones cannot be described as velvety.

Crisp.

This term is applied to tones whose intensity is at least moderate and marked in relation to their duration. A typical dynamograph for this touch-form is seen in Fig. 193.

In this case the player was asked to produce also a tone of the same intensity but "lacking the bite" as he aptly described it. *a* in the figure is the "crisp" tone, *b* a tone of equal intensity but lacking the "crisp" quality. The difference is in the duration, more particularly in the release. In *a* the pressure is very quickly released to the zero point (from *d* to *e*); in *b* it is more gradually released (*d* to *e*), the descending line being less steep than in *a*. If pedal be used, the release of pressure does not affect the tone and this continues to sound, just as it would if pressure on the

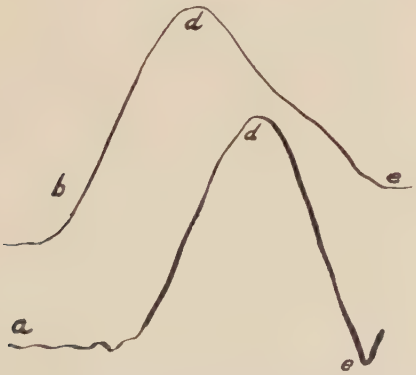


Fig. 193.

key continued. Crispness, therefore, cannot exist tonally, when pedal is used unless the latter be taken *staccatissimo*. The fact that the feeling of crispness persists for the player, regardless of the pedal, is another illustration of projecting a muscular condition into the tonal results. For the listener it does not exist, unless he reads the quality into the tone by watching the arm-release of the player.

I cannot refrain, here, from calling attention again to the need of getting away from eye-impressions in any analysis of auditory tonal qualities. So many qualities are read into the piano tone by the eye, and this is so often done, that it is very difficult for even an experienced listener to dissociate the two sense-impressions.

Bell-like.

Tones on the piano are frequently described as "bell-like". A curve for such a touch-form is that at *a*, Fig. 194, in which *b* represents a curve for a tone of equal intensity but lacking the bell-like quality. This quality has, as its chief characteristics, a percussive beginning, moderate or great intensity, and shortness in duration, a description that fits very closely the manner of producing tone on a bell. The player imitates the impact of the clapper against the bell edge and its rebound from it. Here, too, the use of the pedal will weaken the bell-like quality for the auditor, because the latter does not "hear" the impact pressure and subsequent release. The quality may well persist in the imagination of the player, reënforced, as this is, by the kinesthetic sensations of tone-production. Bell-like thus becomes closely related

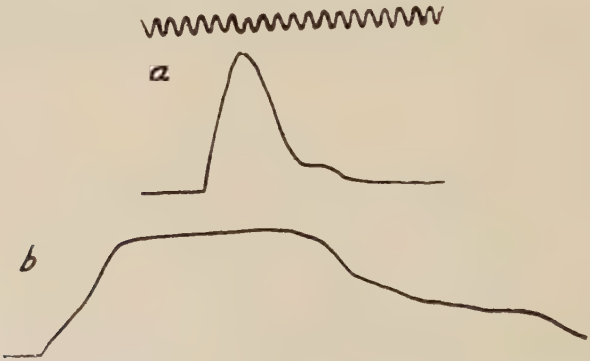


Fig. 194.

to crispness, the similarity being shown by the parallel outlines of the two curves.

Dry.

Dry, so far as I have been able to learn, when applied to a tone, is used either in the sense of uninteresting or to convey the impression of lack of colour. Colour in the piano tone-complex results from the presence of the tonal elements. It is obscured by the predominance of the noise-elements: finger-key impact, key-bed impact, hammer-string impact, hammer-check impact and friction among the action parts. These elements cannot be shown directly by the method of recording here used, but their effect may be seen in the percussiveness (noise) and small amount

of intensity (tone) of a curve for such a quality, Fig. 195*a*. The sharp rise in the line indicates the percussive touch, and the relatively small amplitude (height) shows a tone of little intensity. It is a type of touch in which the impact noises relatively overshadow the tonal elements.

The duration is variable, as shown in the two illustrations at the top of Fig. 195, but the relationship between noise and tone may remain in spite of variations in duration. The essential characteristic is the increased ratio of the noise-elements to the absolute amount of tone. With great intensity the tonal-element necessarily increases and since its duration is much greater than that of the various noise components, the ratio between noise and tone would change,

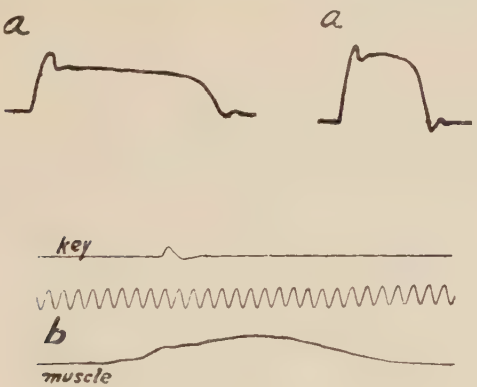


Fig. 195.

and with it the quality of the sound-complex. No comparison in amplitude can be made between the two figures since in Fig. 195*a* the key-depression was magnified approximately 6 to 1, whereas in Fig. 195*b* the key-depression is actual displacement. This difference applies also to other figures in which muscular contractions are given. All percussive tone-production on the piano is accompanied by noticeable noises, which cease after tone-beginning. Therefore, if the tone also ceases at this moment, the noise is sufficient to overshadow the tone, since with an increase in tone, goes a necessary increase in noise. This is the type of touch used for the two closing chords in Debussy's Minstrels, which the composer has marked "sec" or dry. The muscular reaction to a "dry staccato" is interesting. A dry staccato, from the definition given in the preceding paragraph, intensifies, still more, the

preponderance of noise over tone. The noise-elements in tone-production upon the piano are largely present only at tone-beginning. After tone-beginning the tonal elements are present, with no noise until tone-ending. If we produce a dry staccato, therefore, we rob the sound of the tonal value of duration. We reduce tone to a minimum, without in any way reducing the noise-elements. Fig. 195*b* shows a very marked muscular contraction and just a bit of key-depression. The relaxation period is considerably longer than the initial contraction period, and especially longer than the duration of key-depression. The rise in contraction after key-depression may also result from the contraction of the muscle as an inhibitor of hand-ascent. The rather marked amount of muscular contraction, and the extremely small bit of key-movement makes this touch-form similar to the vibrato fixation or inhibition.

Brittle.

Brittleness is associated with sharp edges, and absence of plasticity. A brittle tone, accordingly, should be one of abrupt beginning, moderate to great intensity, and variable duration. Fig. 196 gives an example of the dynamic curve obtained with

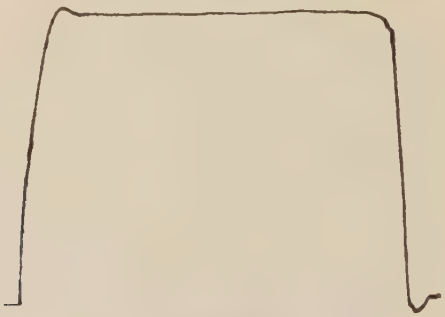


Fig. 196.

such a touch-form. The tone-beginning is very abrupt, and the amplitude large. The abruptness of the beginning plus the intensity give the tone its necessary sharpness. It was impossible to produce a brittle tone for the weak dynamic degrees ; nor could it be done by using a non-percussive touch, except when the entire arm was stiffened and jerked into the key. This spread of muscular contraction is itself an indication of the intensity needed for a tone of such quality. The abruptness plays over into the release which in Fig. 196 is as abrupt as the beginning. This abruptness of release can only be transferred to the key in an apparatus arranged as in

these experiments. The lack of elasticity in key-movement makes it impossible to bring the key up more rapidly than its own momentum, by releasing the finger more rapidly. That is to say, the key-ascent itself was not as abrupt as the descent of the line in Fig. 196. This descent shows an extremely rapid release of pressure, and consequent withdrawal of the hand from the key. The key-ascent, however, does not parallel the hand-ascent. Under key-release this difference is illustrated. (Fig. 204.)

Singing.

A " singing " tone, as its name implies, is one in which duration plays the most important part. Its intensity will be moderate, its beginning as smooth and non-ejaculated as possible. A tone of very weak intensity does not " carry " on the piano, on account of the marked *diminuendo* quality of all sustained piano tones. These characteristics are shown in Fig. 197*a* which is a typical curve

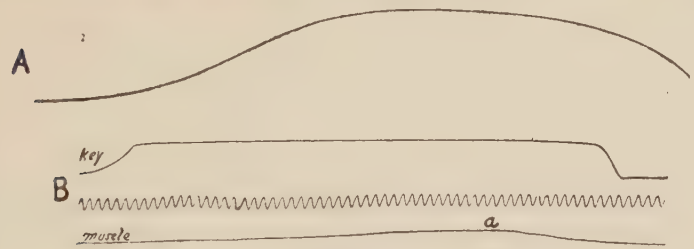


Fig. 197.

for a singing tone: moderate amplitude, long duration, and gradual attack and release, as a result of which percussion and the abrupt, noisy, tone-beginning are absent. All singing tones that I recorded were produced by a relaxed arm, and in all cases the pressure was either sustained or increased after tone-production, although the maintenance or increase, of course, could not actually affect the tone, which diminished just as rapidly as if less pressure —just enough to keep the key depressed—had been used.

A further instance of the dynamic curve for a singing tone is given in Fig. 206 where the actual range of key-movement is also shown and compared with the great amount of imaginary tone-control.

The muscular contraction in the production of a singing tone naturally parallels the imaged duration and shading of the tone. In the figure just referred to, the dynamograph registers an increase in pressure after the key is fully depressed. Accordingly, when

we record the contraction of the muscles, we should find a similar increase in contraction. One typical curve together with the key-movement is given in Fig. 197*b*. The greatest height in the curve of muscular contraction (at *a*) is not reached until well after the key has been fully depressed. In fact, it is closer to key-release than key-depression. All this increase is wasted effort, of course, so far as its effect upon the tone is concerned. Nor do we find good pianists normally using much of it. It is a favourite device of the emotional amateurs who read all sorts of pathos and romance into the long-suffering piano tone. In the record in question, the key was actually depressed through arm-weight, without marked contraction of the flexor muscle. This contracted later.

Repression.

The production of tones through considerable muscular repression demands a word of explanation on account of the frequency with which it is used in the playing of some pianists. The entire muscular system of fingers, hand, arm, and shoulder is placed in a state of hyper-tension, and either enough of an added stimulus is given to the appropriate muscles to cause the fingers to reach the keyboard and to produce tone, or the trunk and abdominal muscles are relaxed and the entire trunk lowered sufficiently through gravity. At times the fingers rest upon the key-surface beforehand. (See Fig. 8, The Skeleton.) Thus a staccato tone or chord is played with a rigid hand, arm, and shoulder in the belief that this muscular condition will produce a tone of a quality differing from a tone of similar intensity and duration produced with a relaxed arm. Before illustrating this touch-form, I must call attention to the fact that such a state of rigidity is not to be mistaken for the normal and necessary rigidity which varies with the tonal intensity, examples of which have already been given in sufficient number. In this case we have maximum rigidity for the production of a tone of relatively little intensity. When the force of such a touch is recorded, and also that of a touch of apparently the same intensity but produced without repression, we get what was to be expected : a softer tone, the typical dynamic relation between relaxation and rigidity, and more noise for the rigid condition. The difference is shown in Fig. 198 on a highly magnified scale, so that the differences in height of the two curves, which reflect differences in tonal intensity may be readily seen, even when these differences are very minute. *a* shows the " repressed " or stiff form, *b* the more relaxed. The apparent difference in quality is again one in intensity. I can see no gain in this rigid touch. It consumes much

energy that is entirely wasted since the mechanical object of physiological rigidity : force of stroke, is neutralized by the repression. It may possibly convey to the player an intensity of feeling, but this cannot carry over into the sound. Its only value lies in the speed of getting away from the key, as in *staccatissimo*. Here it may be useful : the vertical release of *a* in Fig. 198 illustrates the point. But when it is used for tones of even slight duration it is tonally and muscularly useless, hence must be classed as an incoördinated movement. When we consider the great difference in muscular coördination here represented, it is easy to under-

Fig. 198.

stand the qualitative difference assigned by the player to the tone. The intensity of the repression, including at times the cessation of all breathing, so as to fix the chest cavity firmly, may readily be imagined. The musculature system of the entire body, at least that of the trunk and upper limbs, is fixed in a state of hypertension, which is largely maintained through the tone-production itself. The tonal intensity desired is so small, however, that a bit of relaxation, let us say in the trunk region, is all that is needed. Such muscular states, as the James-Lange theory of emotions shows, are inseparably connected with the emotional states ; in fact,

they are the emotional states, in many instances. Accordingly, the player reads these emotional qualities into the tone itself. The auditor, however, especially if he be listening with closed eyes, gets nothing more than a relatively soft, short tone. No element of repression exists for him.

Surface Tone.

A form of touch quite common among inexperienced pupils is the type generally described as a surface touch. The pupil, as we say, fails to get down into the key. The muscular reason for this failure is that the contraction (flexor) which sends the finger down to the key ceases before tone is produced. As a result, the key retards the finger partially or completely. If the contraction of the flexor muscles continued after the finger touched the key-surface, the key would be depressed and the " surface " quality of the tone would be lost.

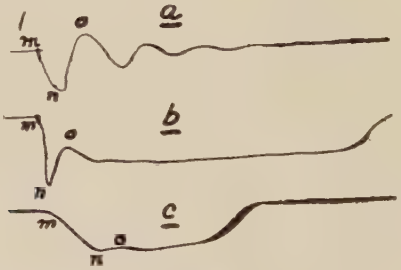


Fig. 199.

This may be demonstrated by means of the mechanical arm and a spring balance. When the part of the arm corresponding to the finger is permitted to fall upon the balance of its own weight (which in this case is the mechanical equivalent of muscular contraction before the key is reached), the curve at *a*, Fig. 199, which traces the movement of the balance level, results. The impact is momentary, and, on the principle of action and reaction, the balance pushes back the finger, reaching its level after a few oscillations. When, instead, the appropriate muscles are contracted at the moment of finger-key impact, the curve at *b* results. The initial fluctuation is the typical percussive adjustment, but the point *o* is considerably lower that the similar point in *a*. Pressure is sustained. If the finger be permitted to rest upon the key-surface and the flexor muscles are then contracted, we get the curve at *c*. The percussive jerk has been eliminated, the key is more slowly

depressed, shown by the slant in the descending line *m* to *n*, as compared to similar points in the other two curves; and the key is held depressed as at *b*. (The chance difference in the duration of this depression between *b* and *c* does not affect the problem.) Similar results are obtained when we record the muscular contraction. Fig. 200 *a* shows the contraction and the key-movement for a "surface" tone; *b* the same for a good, musically satisfactory tone, one lacking the "surfacy" quality. In *a* the muscular

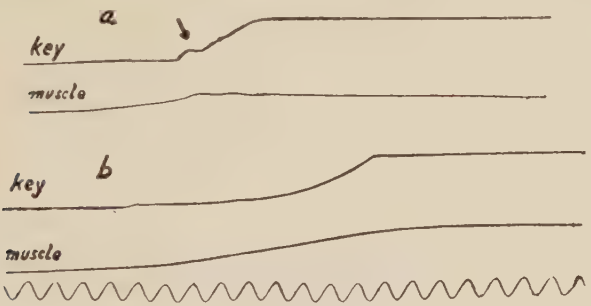


Fig. 200.

contraction takes place before and up to key-finger impact, the initial force depressing the key. After that point no further muscular contraction occurs. In *b*, on the contrary, the greater part of the muscular contraction takes place during the key-descent, since the line representing muscular contraction continues to rise as the key is depressed. The part before key-depression is naturally similar for both touches, since this phase of the movement is present in

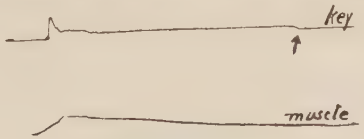


Fig. 201.

either case. The percussiveness—shown by the break in key-movement (see arrow, Fig. 200)—and its absence in the "good" tone-production are proof of the presence and absence, respectively, of the finger-key impact noise. The initial maximal contraction of the muscle in the surface quality may be seen more clearly in Fig. 201, where the key-line also shows lack of maintained pressure.

In this muscular contraction at the moment of impact and its subsequent use during key-descent lies the nucleus of the problem

of tone-production and tone-control on the piano. It is this contraction that is responsible for such pedagogical expressions as "sensitized finger-tips", "feel it in your finger", "weight the key", and others. Instead of stressing finger-lift as seen by the eye, the teacher should stress finger-drop as felt by the muscles. The attention of the pupil should be directed toward the gauging of key-resistance as it affects tone, not to the lift of the finger, away from the key. In each instance of undesirable tone-quality that I tested from this angle, I found an incorrectly timed muscular contraction. In some instances the contraction took place too soon; in others, too late: after the key had reached its key-bed. The best tone-quality for slow-tone production, measured by the tonal beauty of the individual tone, is produced by a minimal muscular contraction at the beginning of key-descent and an increase of this to the desired intensity during key-descent.

Once again the teaching of this is helped not by assisting the finger or hand in its descent, but by interposing additional resistance, either by a slight upward pressure against the outer top-surface of the key, or better by inserting a small spring under the key while the pupil depresses it. This brings key-resistance forcibly to the mind of the pupil and results in the added muscular contraction during key-descent upon which tone-control depends. The moment the key-bed has been reached, however, partial muscular relaxation should set in, since the added pressure is no longer needed.

Pearly.

The word pearly as applied to piano tone is familiar to all pianists as the "jeu perlé" of the French and the "Perlende Gelaüfigkeit" of the Germans. When we record this touch-form we find that the

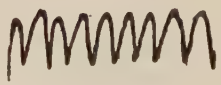


Fig. 202.

pearly character is the result primarily of a non-legato touch. Each tone is as distinct from its neighbours as the tempo permits, while the intensity is, under normal conditions, fairly constant, and seldom great. The ingredients that go to produce the pearly tone-quality are non-legato, dynamic steadiness, rather weak intensity, and fairly great speed. This points to a transfer from the visual field

where a "string of pearls" presents much the same sensorial characteristics. A dynamograph record of this quality is given in Fig. 202. The curve does not show finger-movement but only fluctuations in the force of finger-strokes. The relatively small amplitude of the curves records the weak intensity, the evenness of their crests illustrates the even dynamic degrees, and the drop in the line between each two strokes shows absence of weight-transfer and indicates the non-legato character of the touch.

While experimenting with this touch-form, I came across an interesting effect of fingering upon the legato or non-legato character of the passage. If the following sequence of notes be played with the fingering above them, a non-legato (pearly) tone-quality will result. This is explained in the chapter on Weight-Transfer where speed of finger-lift is shown to be one determinant of legato. If the fingering below the notes be used, without instructing the subject as to any change in tone-quality, the result will usually be a more

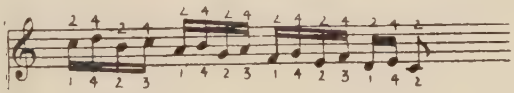


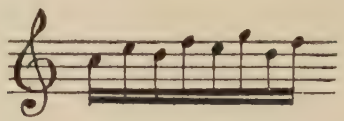
Fig. 203.

legato touch, the dynamograph-record showing noticeably less vertical fluctuations between strokes. The difference results from the fact that in the second fingering no great speed of finger-lift is involved. Such instances show the need for selecting a fingering that will facilitate the musical effect of a particular passage. If, for example, the descending chromatic thirds in the second cadenza of Liszt's A-flat *Liebestraum* are to produce a "pearly" or even "sparkling effect", the use of the fourth finger on black and white keys is desirable. If, on the other hand, a more legato effect be desired, the third finger can be used to advantage on the black keys.

I shall add a quotation that is particularly interesting at this point. It is taken from a letter which Beethoven wrote to Carl Czerny concerning the piano lesson of Beethoven's nephew Carl. He writes :—

"With passages such as these :

I like at times all fingers to be used, also in the following :



so that they may be played in gliding style! Certainly they sound, as it is said 'played in a pearly' (manner), with few fingers, or 'like a pearl', but at times one wants a jewel of a different kind." The quotation is remarkable because it comes from a musician who, least of all, might be expected to analyse the details of touch-forms, being so completely engrossed in the artistic effect of the whole. And yet Beethoven, in a few words, gets at the bottom of at least these two tonal qualities, specifying gliding as legato, and pearly as non-legato.

So long as the speed at which the passage is played is not too great, repetition of finger will normally produce a non-legato touch more readily than change of finger. But, when this speed reaches a certain point, the stiffness characteristic of all very rapidly repeated movements (see Chapter XVI, Finger Staccato) begins to set in. By lengthening the finger sequence, and thus necessarily reducing the speed of actual finger-repetition, we eliminate the danger of stiffness to a certain extent. This difference finds its application in the fingering of the ornamental figures, such as the mordent and the turn. Here a change of fingering facilitates the clearness of the execution. The inverted mordent C D C, for example, is better played 1–3–2 or 2–4–3 than 1–2–1 or 2–3–2. With finger-repetition on the same key the stiffness which sets in whenever a rapid alternating movement is made, frequently interferes with the clear, delicate performance of the ornament. Finger-repetition with a change of key does not have as marked an effect.

Key-Release.

Tone-quality is also affected by the time of key-release. But not by the manner of key-release, since tone-cessation begins only when the damper touches the string. The effect which variations in finger-speed have on key-descent, coupled with the widely accepted, but erroneous notion of elasticity in key-action, has caused players and teachers to conclude that the speed of key-ascent can be controlled by speed of finger-ascent. Up to a certain point —the speed at which the key ascends freely as the shorter end of the key-lever—this is true. Beyond that point the speed of key-ascent cannot be increased. We may jerk the finger away from the

key as rapidly as possible, but the key will take its time coming up, and the finger, in such a case, has left the key-surface well before the key has fully ascended. This difference in the speed of key-ascent and that of finger-ascent is clearly shown in Fig. 204, where *a* is the curve of the ascending finger-tip, and *b* the curve of the ascending key. The difference in speed is seen in the difference in the slant of the lines. If key-speed equalled finger-speed the key would ascend along the dotted line. In this particular record the finger-speed was three times as great as the speed of key-ascent. Needless to say, under such conditions the player has no control whatever over key-ascent.

The result is that the staccato tone is never, in its louder degrees, as short in sound as it feels to the player. By lifting the finger or hand from the key with an extremely rapid movement, the player

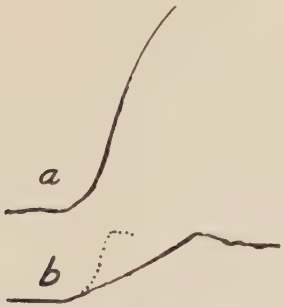


Fig. 204.

creates the illusion—for himself as well as for the listener—of equally extreme brevity of tone. In reality the tone is not as short as the finger-stroke. If we add to this the reverberation properties of the typical studio or especially of the concert hall, we must conclude that the pleasure derived from the brevity of staccato, the true *staccatissimo* is an auditory illusion, resulting from the kinesthetic and visual sensations of the player, and from the visual sense of the auditor. It is another instance of the eye determining tonal quality.

The absence of elasticity or rebound in the key-ascent is clearly shown when we record the movement of a normal piano-key and one in which the rebound is added by attaching a rubber band to the key so that depression of the key extends the band. In this case elastic rebound is present. The two key-movements are given in Fig. 205: *a*, for the elastic return; *b*, for the normal key. The asymmetry of *b* and the symmetry of *a* show that in *b* the ascent

is independent of the speed of descent, the line being both irregular and differently slanted from descent, whereas in *a* ascent is equal in speed to descent. In Fig. 205 the ascent of *a* is just twice as fast as that of *b*.

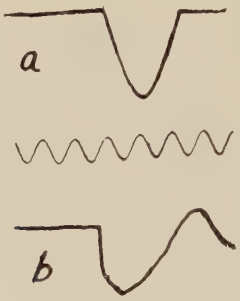


Fig. 205.

Elements of Tone-Qualities.

The qualities selected for illustration have been chosen from many that were recorded because the terms are more familiar than some others. The following deductions, however, are based not only on the records given, but on all that were taken, there having been no noticeable exception in any case.

Tones possessing musical quality, apart from suggesting associations with sensations and perceptions in other fields than the field of hearing, invariably are tones relatively free from the noise elements, with the tonal elements of moderate intensity. They are, further, of moderate or prolonged duration. In other words, they represent stimuli along the mid-range of the scales of tonal attributes : intensity and duration. Such sensations, as experiment has shown, are, other things equal, more pleasant than similar stimuli at or near the extremes of range. A moderately high or low tone, unassociated with other tones or non-auditory images, is normally more pleasant than an extremely high or an extremely low tone ; a tone of moderate intensity, is, under the same conditions, normally more pleasant than a very loud or a very soft tone.[1]

When we bring association into play, however, these reactions usually change. A tone or chord played with a percussiveness and at an intensity at which tonal beauty is decidedly impaired, may readily be reacted to pleasantly if, for example, it marks the climax

[1] O. Ortmann, *Types of Reaction to Music.*

of a phrase, or awakens associations the strength of which outweighs the purely tonal sensations. The strongest and, perhaps, the most misleading of such associations, so far as the single tone is concerned, is that between tone and touch, as a result of which the player reads qualities into the tone which cannot exist physically. All such tonal differences must be differences in intensity, duration, and in combinations of tone and noise. Since this point is denied by many pianists the actual curves for various qualities have been given in the figures of this chapter. They show, without a single exception, that the three elements that make up tone-quality at any one pitch are intensity, duration, and the relationship of noise to tone. Moreover, these three elements are sufficient to account for all tonal qualities, for some directly, for others through the process of association. This relationship is pointed out here in a rudimentary sort of way, and the reason given as to how and why certain combinations of the three elements produce similar sensations in other fields. The details of this phase are primarily psychological questions, and, as such, fall beyond the scope of the present investigation. I might point out, however, that the associations can readily be explained if we grant the existence of " sensation-form ", an attribute of sensation, the reality and the importance of which I have attempted to demonstrate elsewhere.[1]

Tone Combinations.

Objection is often made, and somewhat justifiably so, to the assignment of tonal qualities in the single tone. And in the experiments made, this objection was frequently voiced by the pianists making the records. However, if the qualities assigned by the player to a tone passage do not exist in the single tone, that very fact is definite proof that the so-called tonal-qualities are not inherent qualities at all, but result from dynamic and agogic variations among a succession of tones. Pedal effects, which are qualitative as well as quantitative, are independent of key-manipulation.

At the same time, even these differences among many tones can be shown to result entirely from the three physical variants mentioned. The differences, as a result of which we speak of a Mozart, a Chopin, or a Debussy style, on the piano—I exclude here, of course, the differences of the style of the composition itself—are differences in the intensity and the legato of the touch. An analysis and illustrations of some of these differences will be found in the chapter on Style.

[1] *Sensorial Basis of Music Appreciation,* op. cit.

The Play of Imagery.

It is evident from the analysis of the various qualities which we have been considering that a considerable difference exists between the physical sound produced by the pianist and its psychological resultant. Differences in quantity of sound are interpreted as differences in quality; qualities are read into sound that cannot possibly exist there. A player declares—and justifiably so—that a certain movement produces a certain tone-quality; and the listener maintains—with equal justification—that the tone-quality does not exist. The difference results from the fact that, for the player, the tone-quality is—I am afraid, unfortunately—inseparable from the physiological sensations of the movement of tone-production. The entire muscular system is made tense—but a little of the potential force is used to produce a tone—and a "repressed" tone of specific softness results. But as a matter of fact it does not. Another pianist can produce precisely the same tone with relatively relaxed muscles. And a listener, not seeing the muscular adjustment, will get the feeling of neither repressed nor relaxed tone-production. Strangely enough, imagination is an accepted and much sought after factor in all artistic playing, yet its operation in the case of a single tone is often flatly denied and ignored. Where, then, does it begin to function, at two, three, or four tones; at a phrase, or at a period? The same power of imagery that conjures up pictures for a composition—I think at the moment of Moussorgsky's: Exposition Pictures, and Debussy's "Jardin Sous la Pluie"—is at work for the single tone. In the preceding paragraphs we have the evidence and an attempt at explaining the causes for the imagery. The transfer among various senses, upon which this imagery is based is, I feel, one of the safest postulates that psychology can make in explaining imagination. Particularly because it assumes a sensorial basis common to all senses.

Although such qualities as velvety, sparkling, brittle, and singing, all involve a play of imagery when applied to piano-tone, the extent of this play is most convincingly shown when we record tone-production on an instrument in which the key-depression is not restricted, and compare the result with the production of a similar tone on a normal key-action. The instrument here used was a dynamograph similar to the one used in recording the other qualities described in this chapter. A so-called "good singing" tone was produced by the accepted form of weight-touch. With the key unrestricted in descent the line *a*, Fig. 206, was produced. This means a relatively slow, steady increase of pressure up to a maximum, and a gradual release of weight during key-ascent. The

release of weight is slower than the addition of weight, since the apex of the curve is to the left of the centre. This curve represents the "ideal" tone-production for a single-tone of musical value. (Numerous records by various pianists were made, of course.) Then the instrument was set so that the key-descent was limited to the normal three-eighths of an inch as found in the piano. It produced the curve *b*, heavy line. This begins the same as *a*, but at *b* all further control is lost until *c* is reached. The shaded part of the figure, in other words, three-fourths of the dynamic variation (from *b* to b^1 to *c*) thus exists only in the imagination of the player. He controls the key through but one-fourth of the dynamic range and less than one-fourth of the duration range.

The remaining three-fourths and more represent purely physiological movement, which is then, through the play of imagery, transferred to the tone itself. From a mechanical standpoint, and from a tonal standpoint as well, the entire shaded portion is

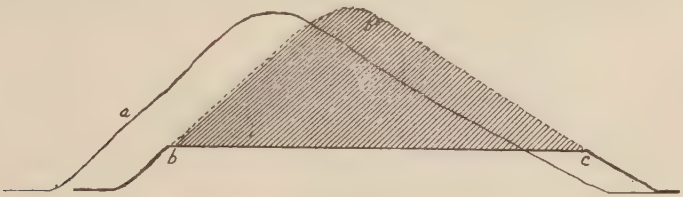


FIG. 206.

wasted work. Emotional effect upon the player may justify the waste, but it does not justify the teaching of the tonal quality as existing in the tone itself.

Illusions are not restricted to any one tone-quality. Its presence in *staccatissimo* I have already mentioned, and it functions as well in all touches in which the variations occur before the key is reached, and after it is lifted, and, at times in others, where the finger-position is used to determine tone-quality. Frequently, for example, the pedal is taken on the last note of a phrase in order to avoid an abrupt tone-ending as the hand and arm are lifted from the key. A person not looking, gets none of the lift or the phrasing; but a person seeing the movement, learns the phrasing and in consequence reacts differently. The player, feeling the phrasing as well as seeing it, reacts differently again. Examples such as these will occur in number to anyone analysing the actual facts of tone-production. They are most convincingly shown when we sit through a piano recital with eyes closed. The experienced pianist may even then comprehend the phrasing, particularly if the material played be

familiar. But it may not be the phrasing actually used by the player; it will probably be that imaged by the listening pianist whose keyboard experience supplies him with a rich source of kinesthetic and visual memories upon which he constructs his imaged phrasing.

Melodic Accentuation.

Closely connected with the question of tone-qualities is that of melodic quality or intensification. In its simplest form, where a melody is played in one hand and an accompaniment in another, the relationship is admittedly one of simple intensity. Conditions become more involved when the melody and accompaniment

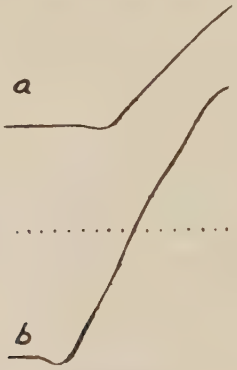


Fig. 207.

are played simultaneously by the same hand, as in the first movement of Beethoven's C-sharp minor Sonata, popularly known as the Moonlight Sonata, or in the familiar Melody in F of Rubinstein. Absolute simultaneity is demanded, but is probably seldom actually achieved by the player. Since the melody key must descend more rapidly than the accompaniment key (for tonal intensity depends entirely upon the key-speed at the moment of escapement) the moment of tone-production will differ unless the key-descents be so adjusted that earlier beginning neutralizes the lag of the slower key-movement. Such an adjustment is extremely difficult, because the rigidity of the two knuckles producing the tones must differ, and experiment has shown that such a condition is opposed to accurate control. The more natural inference is that in melodic accentuation of the type here discussed, the keys actually do not move precisely together, and that the tones do not sound absolutely simultaneously, the difference being too slight to be noticed in

sounds that are sustained. The accented tone will then be the first to sound. Fig. 207 indicates that this relationship exists. *a* represents the curve of key-movement for the unaccented tone, *b*, that for the accented, melody tone. The points of upward deflection are the beginnings of the key-descents. The distances have been magnified and the direction reversed, a rise in the line indicating key-descent. The time-line is given in thousandths of seconds, and, in this particular instance the melody key preceded the accompaniment key by three one-thousandths of a second, and since its descent was more rapid (the line in *b* is steeper) tone-production differed at least by this amount. Such a difference is too small to distinguish with tones and, accordingly, the tones are heard as simultaneous. The fact that the keys travel at different speeds, shown in the figure by the difference in the slant of the lines, shows the physiological principle underlying tone-accentuation at work.

If such an accentuation be produced by finger-stroke, differences in finger-speed will be necessary, the greater finger-speed being

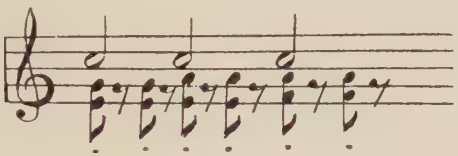


Fig. 208.

used for the accented tone. Such speed, as we shall see later, may be attained by a greater finger-lift. But here the danger of not reaching the keys simultaneously is present. The alternative is to start the two fingers at the same level, but to contract the flexor of the accented finger more strongly than that of the other finger. This is a fine coördination and excessively difficult for young beginners.

The problem is somewhat simplified if the arm can be used in tone-production. In that case the knuckle as fulcrum of the accented tone, is made sufficiently rigid, while that for the unaccented tone is held relaxed. The descending arm then gives sufficient speed to the accented key whereas a moderate finger-stroke will take care of the less intensity of the accompaniment tone. An exercise such as in Fig. 208, is very useful in teaching this coördination. Here the first, second, and third finger (others *ad libitum*) play with a light staccato while the melody tone is held. The finger-staccato forces movement in the hand-knuckles, thus eliminating the sympathetic rigidity in these joints normally spreading from the

fixed knuckle of the melody finger. Once this combination has been acquired—movement in the accompaniment knuckles with fixed melody knuckle—the staccato can then be transferred gradually into the *sostenuto* touch.

The popular phrase of "throwing the arm-weight back of the melody finger" does not accurately express the mechanics of the movement, although it does embody the correct principle. What takes place is the shifting of the arm and hand into the skeletal straight-line position, so that an extension of the skeletal axis of the fore-arm passes through the melody finger. Or else excess muscular fixation approximates the skeletal position. This position is that applied in cases of maximal force-transfer, of which numerous instances have already been given. At the same time to the degree that the melody finger is thrown into line with a rigid structure, the other fingers are thrown proportionately out of line, with the resulting loss in force-transfer.

The skeletal distribution is not the only element of difference. In order to make the dynamic contrast between melody and accompaniment sufficiently marked, an additional difference in the degree of fixation of the various hand-knuckles is needed, which will permit the key-speed of the accompaniment to be reduced to any auditory degree. The problem of the normal pupil is not the difficulty of stressing the accented tone, but rather of doing that without stressing the simultaneous accompaniment tones. And this difference is one of hand-knuckle fixation, not arm-weight.

Fingering.

Since this fixation varies as the distance between the playing fingers varies, and since the spread of activity from each finger to its adjoining fingers is constantly present (see Action and Reaction), it is obviously more difficult, normally, to use adjacent fingers for marked simultaneous dynamic differences than non-adjacent fingers. The physiological hand-division (p. 314) serves as a fundamental selection. The fifth-finger is best adapted to melodic accentuation with simultaneous tones on account of its own group of muscles, contraction of which influences the other fingers least. The more fundamental separation of the thumb is hindered somewhat by the direction of action, which is opposed to the natural thumb-movements, these being horizontal, rather than vertical. The index finger is useful when the lay-out of the piano passage permits its use. In general, adjacent fingers should be avoided, 2 and 4, or 3 and 5, being preferable to 3 and 4, or 4 and 5, even if the piano-keys played are adjacent keys, because the spread of tension from the

fourth to the second knuckle or fifth to third, is less than that from fourth to third or fifth to fourth.

Since the accentuation of the melody tone demands various degrees of hand-knuckle fixation, spreading of the fingers (abduction) should be avoided in the early exercises, and the small hand should be kept within the five-finger position. When the fingers are abducted the fixation in the hand-knuckles is increased, reducing the difference between the accented and the unaccented tones. In the five-finger position, the physiological subdivision of the hand, given on page 314, may determine the order of the exercises.

The first group might use thumb accentuation, which may be done with arm-descent, while the hand-knuckles, which are controlled largely by other muscles, may be relaxed. Even full passive relaxation may be used at first, in which case only the accented

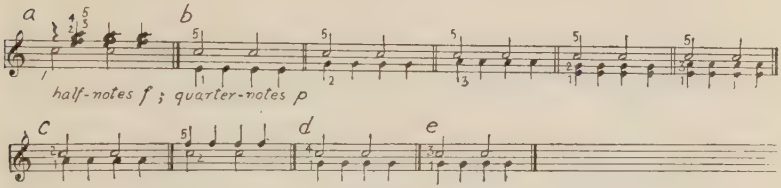


Fig. 209.

key will be depressed. Gradually the finger-fixation should be increased until tone is produced. The simplest form of exercise is given in Fig. 209*a*, which exercise eliminates the lift of certain fingers while others play. Active finger-lift adds a difficulty.

The next group, in point of difficulty, uses the fifth finger (the second subdivision of the hand, Fig. 165*c*) as accented finger. It should first be combined with the thumb, then with the second finger, and later with the others, Fig. 209*b*.

The third group uses the index finger (the third subdivision of the hand) as the accented finger, which may advantageously be combined with 1, then with 5, and later with 4 and 3 (Fig. 209*c*).

The same plan should be followed with 3 and 4 as the accented fingers, the earliest combinations being with those fingers physiologically more separate from them, namely, thumb and fifth finger (Fig. 209 *d* and *e*). In the case of the fourth finger, its proximity to the fifth adds the difficulty of adjacent fingers already mentioned. The 4–1 combination is much easier.

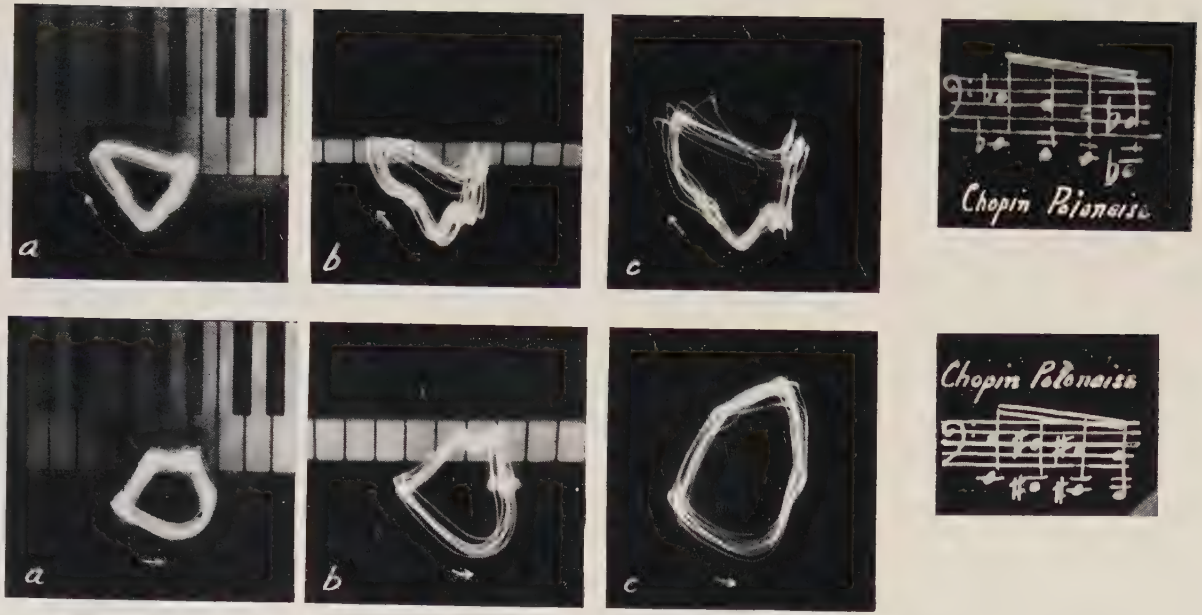
CHAPTER XXIV

Style

In spite of the uniformity of all piano keyboards and of the mechanical principles outlined and analysed in the preceding chapters, the playing of any pianist differs sufficiently from that of any other, to permit us properly to speak of individual " style ". This style adds the so-called personal touch of the player ; it reflects the personality, and is generally supposed to be a kind of spiritual reflex safely beyond the tentacles of analysis. However that may be, the fact remains that the keyboard, tonally speaking, is the only medium through which the player can express anything, from the most obvious effects of accent and tempo to the most subtle variation in emotional colour. Therefore, once again, intensity, duration, and the noise elements will give us a cue to differences in " style ".

A simple and reasonably satisfactory method of investigating some of the rudiments of style is to record the playing by various pianists of the same phrase. The spatial and agogic relationships are, in that case, constant, and the dynamic relationship may be relatively controlled at some fixed point. Fingering may likewise be kept uniform. If the actual duration and intensity were entirely uniform, as the notation, strictly speaking, demands, the tonal results would have to be the same for all records. As a matter of fact, there are always minute differences present, which, on account of their minuteness, escape detection under normal conditions. A few of the following figures should convince anyone that marked physiological variations in intensity and duration are always present and that these variations parallel the emotional effects secured.

In investigating style I shall choose, not the elements of movement which we have thus far considered, but random bits of movement taken from piano literature. One instance is the octave passage, left hand, in the Chopin Polonaise in A-flat where the left hand repeats the diatonic figure, E-flat, D, C, B-flat and later E, D-sharp, C-sharp, B. The figure is definitely fixed, and, being in octaves, does away with variations in fingering, which always affect the geometrics of a movement. Moreover, as an accompaniment figure, and again as a pedal-point figure, variations in its performance



Figs. 210 and 211. Hand-movements, showing individual differences in the performance of the same passage.

[To face p. 362

should be at a minimum. In Fig. 210 are shown the movements of the centre of the hand for the octave passage, left hand: E-flat, D, C, B-flat, repeated many times. Three pianists are represented; tempo and intensity were left to the player. Accordingly, the differences in the curves can result only from individual differences in performance; or in what, for want of a better word, we call style.

Before pointing out these differences I want to call attention to the fact that the motion used in this Chopin passage has long been considered and illustrated as a circle or as a broad ellipse both for the passage in E-flat major, and the same passage in E major. A glance at the curves of Fig. 210 and Fig. 211 shows that, although the movements are curvilinear, they are only somewhat circular; it shows, moreover, that the curve for the figure in flats, differs materially from that for the same figure in sharps (Fig. 211). This

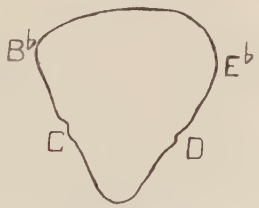


Fig. 212.

difference is a conspicuous example of the effect of the mechanical build of the keyboard upon the movement. As the hand moves from E-flat to D it is pulled away from the keyboard striking D on its way, but not turning immediately, continuing, instead, in the same direction by virtue of the properties of inertia and momentum. A short curve is then made between D and C, and the direction of hand-movement has been completely changed before C is reached. As C is played the hand does not change its general direction but continues to B-flat. At B-flat, however, the direction changes abruptly. From a mechanical standpoint this is opposed to the coördinative principles deduced in earlier chapters. According to these, the arm or hand should continue with no abrupt change in direction, as between D and C, and should curve back to E-flat. It cannot do so because the fall-board of the piano is in the way. If this fall-board were not there, the hand would describe a curve about as in Fig. 212.

The same condition holds for the figure when it occurs in sharps. When D-sharp is reached from E there is an abrupt turn, so that the

movement from D-sharp to C-sharp is practically a straight line, or at any rate, not a convex curve. In fact, in two examples it is slightly concave. The movement from B to E, on the contrary, is a decided curve, allowing for a gradual change of direction, and permitting unchanged direction as B and E are played. In the chapter on Miscellaneous Movements the effect of the fall-board in other figures is shown, hence the flatness of the curves just described cannot result from the particular passage but is a characteristic of all similar changes from rapid forward to backward arm-movements over the black keys. The apparent discrepancy between the keys played and the curves shown is explained by the fact that the centre of the hand was photographed, consequently its projection over the keys would fall approximately midway between the keys actually played by the thumb and the fifth finger.

When the photographs are studied for differences in style, we find, first, a marked agreement in the fundamental geometrical contour of the curves. All the figures in Fig. 210 agree in a general form, somewhat resembling the case of a grand piano. Those in Fig. 211 likewise agree; here the figure has three straight sides and one curved side.

We find, further, however, minor variations showing individual differences. In both Fig. 210 and 211 similar letters refer to the same pianist. A person not knowing this, after familiarizing himself with the method of recording and interpreting the movements, could pair them off without great difficulty. There is, for example, greater agreement in the superposition of lines between Fig. 210*a* and Fig. 211*a*, than between Fig. 210*a* and Fig. 210*c*, or even *b*. *a* and *b* both Figures show less movement and greater accuracy of repetition than *c*.

It is, of course, unsafe to generalize from a single example. I feel, however, that such differences as these are a good index to some general features of the pianist's style. Thus figures such as those at *a* are an indication of a high degree of technical accuracy, and upon this the dynamic gradations largely depend. Then, too, there is noticeable economy of movement in *a*, which is one of the principles of coördination. The curves at *c* frequently reflect an emotional stress, as a result of which technical accuracy is made subservient to the emotional content of the passage. In the case in question, this emotionalism does not lie in the left hand octaves but in the accompanying right hand chords, which were readily imaged by the pianists making the records, even though the right hand was not actually playing. This image, as a matter of fact,

probably helped to determine certain details in the left-hand movement.

In Fig. 213 the two types of curve, that in E-flat and that in E are shown together, illustrating the change from one to the other. This record was not made by any of the three pianists represented in Figs. 210 and 211, hence differs in detail from them. The fundamental characteristics of the curves are of course readily discernible. Beginning at E and passing D-sharp, C-sharp, B, back to E gives a curve having the form of those in the similar passage of Fig. 211. It was twice played. Then the hand moves in a straight line from B to E-flat and the figure takes the form of those in Fig. 210, ending finally on E-flat. I have added the letters at the points where the fingers strike the keys. Since the curve represents the mid-point of the hand, the lines, as already mentioned, naturally cannot coincide with the keys struck, but lie approximately midway between these.

In no one of the photographs is the curve an actual circle. The curved parts from a key to the next key played are all deviations from true circles. Accordingly, between no strokes of this movement is the motion made from a single joint. (See Chapter VI, on the Geometrics of Movement.) Instead, it involves forward and backward movement, abduction and adduction of the upper arm, flexion and extension of the elbow and flexion and extension of the wrist, with, perhaps, some ab- and adduction of the wrist added. It forms a pretty example of the curvilinearity of basic movement, upon the path of which occur the finer movements of the hand or the fingers that actually produce the tones. The path described by the arm is not extremely rapid, even when the passage is played at the prescribed tempo. On this relatively slow basic elliptical movement the four-times more rapid hand-movement is superimposed. A similar instance is found in the repeated octaves of Schubert's Erl-King, which are frequently played with a relatively slow rise and fall of the wrist while the repetition takes place.

Similar differences are found in passages adding an element of change to the one of repetition. In fact, such passages magnify the variation we have been considering. Fig. 214 and Fig. 215 are photographs of the movement of the right hands in two such passages. The observer stands behind the player, with the eye on an approximate level with the keyboard. In Fig. 214 the octaves played were, ascendingly C-G-E-B-G-D-B-F-D-A (ascending fifths and descending thirds), in Fig. 215 they were C-E-G-E-G-C-G-C-E. The details of the two curves are, therefore, only approximately comparable. Yet in spite of this limitation, the great difference in style in the performance of the two pianists is clearly marked.

Fig. 214 shows an unusually fine coördination, the amplitude and the mode of repetition being practically constant. Fig. 215, on the contrary, shows marked fluctuations, inhibitions of movement before the key was played (as at the point where the hand returned from G to E, marked *m*, which should be as low as E), and irregularities in the amplitude and in the lateral transfer itself. We may conclude that the movement in Fig. 215 is relatively incoördinated, since the passage played did not require these variations. The conclusion from a single record may seem unwarranted, but receives additional verification from Fig. 211*a*, and *c*, made respectively by the same players. This difference in amplitude and irregularity, which I have pointed out as a determinant of style, is present in each record made. I add another example: Fig. 216*a* and *b*. The movement was that made in playing the interval of a twelfth rapidly with many repetitions, in octaves, a type of movement described in detail in the chapter on Lateral Arm-Movement. It is a movement of absolute repetition, and, naturally, one of physiological repetition. In Fig. 216*a* we note the expected high degree of accuracy, in Fig. 216*b*, the same movement less accurately made. The observer stands behind the player, at the keyboard level. In one case the lines show little deviation from the points of key-contact; in the other, there is considerably greater fluctuation, both in the path traversed and at the points of key-contact. The tempi were the same. The constancy with which this difference is met points to a difference of style, reflected in the geometrics of movement.

The curves of Figs. 214 and 215, showing the mixed figures, are interesting also from the standpoint of lateral arm-movement itself. In one case the elongated eight, or bow-tie curve is modified, the loop being retained at one end only. This is because the equal tonal intensity demands equal amplitude of movement (see Chapter XIII), and since the descending third is a shorter interval than the ascending fifth, this amplitude must be reached in less lateral distance. The two lines, therefore, coincide in that part of the movement. At the same time, since all abrupt movements add a difficulty to physiological coördination, a passage such as the one given, is more difficult to play than one permitting a change of direction less than direct reversal. The difference need not be in the mere striking of the correct keys, it may also be in the control of intensity. An abrupt change of direction is normally associated from a mechanical and physiological standpoint with dynamic accent. Consequently, it is easier to accent the tones at the points of the curve than those at the loops. This is further

Fig. 213.
Combination of Figs. 210 and 211.

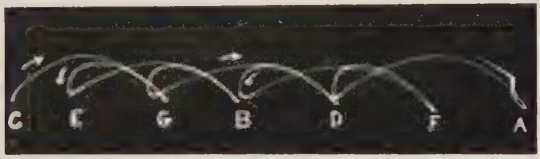


Fig. 214. Superior coördination in the given passage.

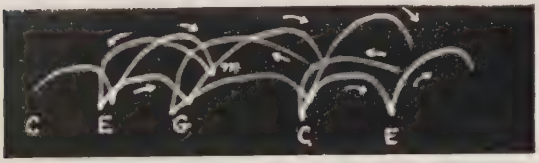


Fig. 215. Inferior coördination in the given passage.

Fig. 216. *a*, *b*. Incoördinated movement in a rapid lateral arm-transfer.
Compare with Fig. 59, *b*.

[*To face p.* 366

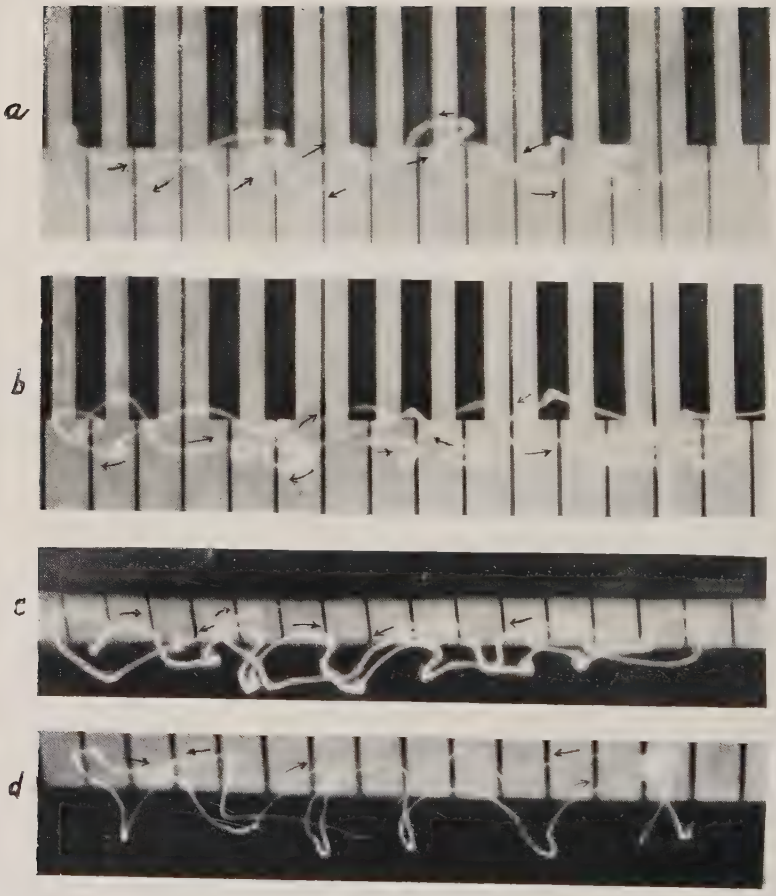


Fig. 217. Individual differences in the performance of the same passage.

[To face p. 36

determined by the factor of speed. If the time interval between each two tones is a constant, the hand must travel twice as fast between C and G than between G and E, for the distance is twice as great. And force is the product of velocity and mass. We may write as a principle of movement: Lateral movements of equal distance, other things equal, are conducive to tones of equal intensity, movements of unequal distances, to tones of unequal intensity. And, as a corollary: wide skips at moderate or great speed are associated with accent.

This accounts for the extreme difficulty of crossing hands for single tones in a *presto* or even *allegro* movement with *pianissimo* tone-production. The logical pedagogic procedure to follow, if the problem be the production of equal tonal intensity at moderate or great speed, is from small equal lateral displacements to larger ones, from scale passages to interval passages, without reversal of direction.

In Fig. 215 some of the tones played permitted a return over the same keys, for example E-G-E-G. This should produce the typical loop form of lateral transfer. It may be seen between E and *m*, and also, though unequally, between G-C-C-G and C-E-E-C, thus bearing out the conclusions on the curvilinearity of the rapid lateral shift.

In Fig. 217 comparison may be made among the records of a more complex technical passage: the first four measures of Chopin's Etude in G-flat, Op. 10, No. 5, more familiar as the Black Key Study. The complexity of this passage, compared with the figure in the Chopin Polonaise, leaves much more room for individual variation. In fact it is at first difficult to recognize the curves as records of the same notes. The loops at the left-hand end of the figures (the lowest pitch-point of the passage played) are quite different, as are also many other points along the curves. The fundamental direction relationships, however, at least for *a* and *b* remain the same. In the descending part of the curve, including the left-hand corner there are four forward and backward shifts, rather equally distributed; in the ascending part there are two shorter forward shifts followed by a longer one. This agreement is to be expected. Individual differences cannot well lie in the gross movements, because the same keyboard passage will not permit variations in the fundamental directions of movement. The differences, as *a* and *b* of Fig. 217 show, are found in the smaller movements of wrist, hand, and fingers. *a*, Fig. 217, shows less arm-movement and more finger-movement than *b*. *b*, incidentally, was made by a small hand, which avoids excessive stretches of

finger abduction by substituting fore-arm and upper-arm movement for it. For the hand making *a* this was unnecessary, hence, somewhat less hand-movement (as part of arm-movement) is noticeable.

Since this figure is played entirely upon black keys, the forward-backward arm-shift is interesting evidence of the extent to which this arm-movement is used in actual playing. The arm is pushed forward to accommodate the thumb. Without this shift the other fingers would have to play in an awkward, curved position, or they would strike the keys too near the fall-board of the piano. (The flattened portions of all the curves on the side nearest the fall-board show again the restriction which this places upon technical movement.) The excessive curve is poor because finger-flexion and abduction do not go well together ; the playing too near the fall-board makes accurate dynamic control difficult by shortening the key-lever too much. However, this spatial relationship in no way demands the entire forward shift which we find in the photographs. This shift is used, as we have seen in other instances, because it is conducive to freedom and ease of physiological movement. There is no evidence in the records of Fig. 217 of any spatial preparation (which would show in greater contrasts of brightness), in spite of the fact that the passage can be played in this manner, eliminating all forward shift.

In *d*, Fig. 217, is seen a defective performance of the same passage. In the descent one forward shift is entirely absent, while the entire figure is characterized by an excessive forward and backward arm-movement, not at all demanded by the keyboard relationships. The result of such a performance is dynamic irregularity and spatial uncertainty, for it violates the principle of coördination that demands a minimum output of muscular energy. The projection over the keyboard is not accurate, but the movement curve itself is not foreshortened.

In records of other passages, made by various pianists, differences in the lines of movement were clearly discernible in each instance. It is my belief that in these differences lie the variations which result in individuality or style. The evidence for this belief is at hand : in no instance were the movements of two pianists exactly alike, and in every instance the variations were in keeping with the generally accepted version of the style of the particular performer. Technical perfection is reflected in the exact superposition of a repeated movement as at *a*, Figs. 210, 211 ; and in a minimum of movement and angular displacement as in Fig. 216*a*, both figures having been made by the same pianist. Technical inaccuracy, whether the result of inefficient technique or emotional abandon,

PLATE XLIX

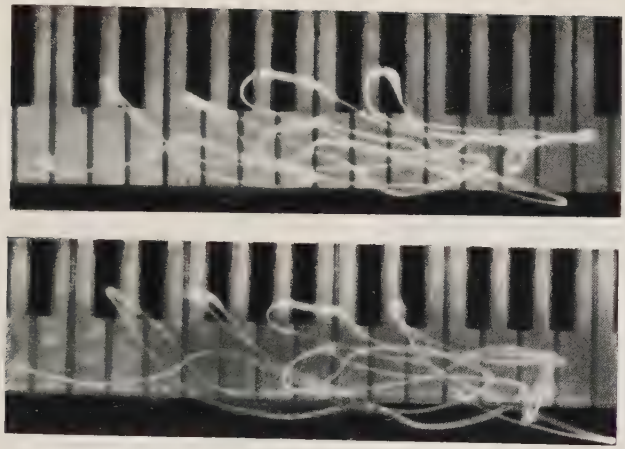


Fig. 218

Fig. 218 and Fig. 219. Effect of repetition upon movement.

[To face p. 368

will show itself in deviations from a fixed path in repeated movements, and in excess movement otherwise, as in *c*. Figs. 210, 211, Fig. 216*b* and Fig. 217*d*.

Repetition.

In tracing individual differences of style to variations in the geometrics and dynamics of pianistic movements, the question naturally arises: what variations will repetition introduce when the records are made by the same player? To what extent does a player actually repeat each movement when playing the same passage twice or more in succession?

If the human organism were more fixed in its "modus operandi", we should expect an absolutely complete repetition. But the study of the muscular, circulatory, and neural systems gives a glimpse into the field of variable response which characterizes all human behaviour. The extent to which variations in the repetition of a phrase occur is important in the question we are here considering because, if these variations are sufficiently great, they may account for the differences which we have just attributed to style.

Figs. 218 and 219 illustrate the variations of repetition: Fig. 218, the curves for measures 27 and 28 of the Chopin Berceuse; Fig. 219, the first seven measures of the Chopin E minor Waltz, op. post. Although the curves vary in certain details, they show considerably less variation than that between records of two pianists. It is such differences as these that account for some of the variations in the several performances of any one artist. "That did not go so well" is an expression frequently heard after a piece is finished. The player is well aware of the defects. The curves of Fig. 218 and 219 show that small variations occur with each repetition, and that in addition to the greater differences in the styles of various pianists, there are also smaller differences in the style of any one pianist.

This may seem somewhat platitudinous. But the illustrations have been included to show that accompanying these differences in style are differences in the geometrics of the movement. For each difference the mechanical phase of the movement varies, hence also the physiological phase. Each variation in a line, no matter how minute, results from a variation in the muscular coördination. The variations shown in Fig. 218 and Fig. 219 cannot result from a chance shift of the position of the point of light in its attachment to the hand, because in that case they would be uniform throughout the figures. This uniformity is not present. In the E Minor Waltz, for example, only the first two loops show a marked difference, in that the lines fail to meet at the outside (lower) points.

These variations within the individual increase with the technical complexity of the passage. Scales and arpeggios, not complicated by any special dynamic or spatial demands, show practically no variation, whereas intricate figures, rapid wide leaps, as at the end of the first movement of Schumann's C Major Fantasia, show, at times, considerable variation. The extent to which a passage has been technically mastered, may be adequately measured by the accuracy with which the movement can be repeated. Records obtained from kinesthetically untalented pupils show variations in movement so wide in extent that they can scarcely be recognized as covering the same notation. At the other extreme stand the great technicians who repeat movements with extreme accuracy.

Variations within the individual depend further upon the range of movement ; small movements showing less deviations from any norm than wide movements. This is in accordance with the fact, that the perception of a deviation depends upon its ratio to the norm, a relationship existing not only in the field of kinesthesis, but in all other sense departments as well.

In the preceding paragraphs the dependence of style upon geometric variations in the movements of the player was pointed out. The other two factors determining style are : dynamic and agogic variations. The method used for recording the geometrics of movement does not show dynamic or agogic variations. In order to record these, some form of dynamograph is needed. The instrument described on p. 134 is quite serviceable, although it has the disadvantage of not producing tone. Accordingly, the records here shown were checked by the method described on p. 241 in order to make sure that chance fluctuations or the abnormality of non-tonal procedure did not determine the contour of the curves.

I select for illustration the first phrase of the trio of Chopin's Funeral March, from the B-flat minor Sonata. The notation is given in Fig. 220, which shows the dynamograph record of four pianists. The conditions restricted the playing to a given tempo, each player being otherwise free to play the melody as he felt it. Here again we find wide variations in dynamics. In curve A the first tone is quite loud, pressure is maintained ; there is a drop in intensity from F to E-flat, a rise from E-flat on, with B-flat as climax, then a *diminuendo* to A-flat. In record B, the first F was played softly, a conspicuous crescendo made up to C as a climax, with the following B-flat and A-flat somewhat softer. In C, the crescendo is much less marked and in D it is entirely absent, the entire phrase having been played at a uniformly moderately soft intensity. The lettering given is only approximate, since, on a

dynamograph of this type the actual moment of tone-production is not indicated by the curves. Inferences as to tempo rubato within the phrase are, therefore, subject to error.

The variations in the degree of weight-transfer are equally well marked. In record D, the first F was played staccato (with the pedal sustaining tone) because the line drops back to the original level. In C and A the pressure immediately after percussion was noticeably retained ; somewhat less so in B. The latter part of D, however, shows a marked degree of weight-transfer, eliminating all sudden fluctuations. This leads to the assumption of a non-percussive touch, which, as a matter of fact, was used in the playing of this record. The degree of weight transferred is particularly

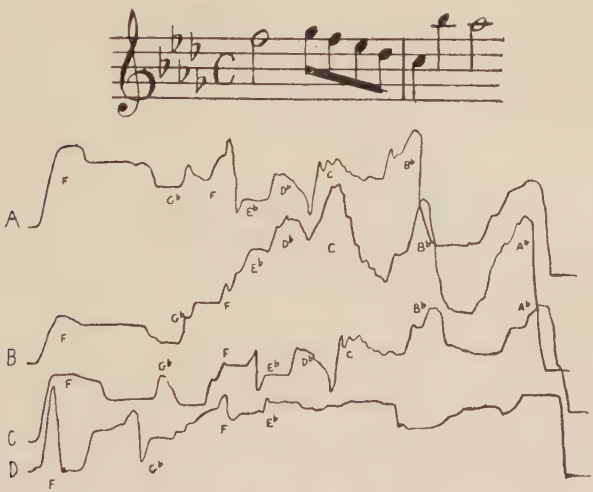



Fig. 220.

noticeable by comparing the troughs in A and B for the tones B-flat and A-flat with the noticeable plateau of D, for the same tones.

The instrument used was, of course, quite sensitive, and many of the dynamic fluctuations recorded would not affect tone since the key may have been fully depressed when they occurred. None the less, they are of sufficient magnitude to show that they are individual variations, hence operative as well before and during tone-production as after. Only dynamic variations have been analysed, but the agogic equivalents, typified by the *tempo rubato*, are no less marked, and between the two, can explain many differences in style.

I could pursue this investigation much further to advantage, but it is leading away from the purely physiological field into the psychological. The dynamic and agogic variations, however, responsible for the stylistic variations, are, after all, a result of differences in muscular coördination, and, as such, fall within the scope of the present investigation. When a technically untalented pupil plays the passage in question, we get, as a typical curve, that shown in Fig. 221. When this is compared with Fig. 220 we note a marked lack of control in dynamic values. Tones are accented that should receive no accent, others that are prominent, are touched but lightly. Accordingly, the artistic rendition of a passage on the piano demands a high degree of dynamic control. We must be able to increase or decrease muscular action by very small amounts. The spread of tension must be finely controlled. Nor should the practice of such control be unduly postponed. The question of balance, that is to say, of bringing out a melody and subduing the background, can be taught quite early without any

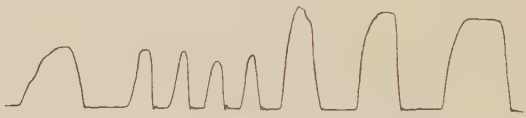


Fig. 221.

noticeable difficulty. The reason for this is the fact that the organism has already used force variations: in grasping and lifting objects of various weights, in walking or running at various speeds, in striking, pulling, or pushing against various resistances. True, ten years later, the pupil will probably use a different coördination to secure similar effects, because the weight of the anatomical parts, and the strength of the muscles will have changed, but the ability to secure some difference in dynamic value is present at the beginning of instruction, and is a far more fundamental coördination than dexterity.

The word style, however, is used not only to distinguish the playing of one pianist from that of another, but also to differentiate the works of one composer from those of another. We speak of a Mozart Style, a Chopin Style, a Bach Style, meaning thereby characteristics in the manner of performance as well as in the manner of composition. Here, too, an interesting field lies open for the patient investigator, for such differences of style have just as clear a physical basis as those we have been considering. A detailed treatment of this phase is not a part of the present inquiry.

Nor have I pursued the investigation far enough to warrant broad conclusions. I shall select a few records merely to serve as illustrations of such differences in style. Take, for example, the manner in which an *allegro* scale is played in a Mozart Sonata and in a Chopin work—such as the F-sharp Impromptu. Fig. 222 illustrates

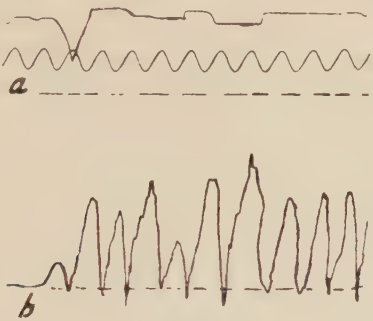


Fig. 222.

the difference. The Mozart scale, *b* in the figure, is decidedly non-legato, the needle of the dynamograph showing no legato between any two tones, since the fluctuating line drops to its original zero-level each time. The Chopin scale, on the contrary, *a* in the figure, is very legato, the dynamograph tracing being practically horizontal,

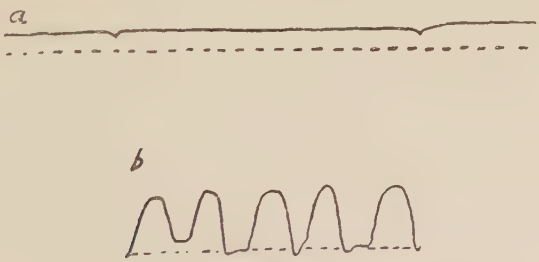


Fig. 223.

with the one exception of a drop as the thumb was played. The fact that several pianists produced similar records, with a difference in the degree of legato as the chief characteristic, points to this physical quality as one of the determinants of style. A scale in the Mozart style—I am well aware of the many exceptions—is, other things equal, less legato than a scale in the Chopin style. Or, take again a very light legato, such as that used in the softer parts of

the melody in a Chopin Nocturne, and compare it with the touch used in the figuration work of Debussy's L'Isle Joyeuse. The difference, Fig. 223*a* and *b*, is one of intensity, duration, and legato. The Chopin melody *a* is very soft, slow, and played with sustained pressure ; the Debussy passage is louder (shown by the height of the line), faster (shown by the horizontal extent of each loop), and non-legato. That is to say, such differences in style are differences in the intensity, duration, and connection of the tones. In both figures the sensitivity of the recording instrument makes them very obvious ; in the actual performance, the intensity and legato differences are often very minute, and in that form readily escape detection by the average observer. Therein lies the value of the graphic method of analysis : it records differences too minute for the eye or the ear to detect clearly. The reproduction of particular effects is a relatively easy matter for an accomplished pianist once he knows the exact nature of the effect. And in many cases his experienced observation enables him to imitate directly. But the matter changes where inexperienced pupils are concerned. The method of imitation is here pedagogically often inadequate and an exact knowledge of the nature of an effect is frequently the only means of making the solution clear to the pupil. A pupil may not understand what a " pearly " touch is, but he can readily be made to understand what its mechanical equivalent, a non-legato touch is.

The Pedal.

The physiological mechanics of piano techique should include, as an interesting and certainly an important part, an analysis of pedaling ; for, whatever tone-colors the pianist draws from the instrument, these are largely modified and controlled by a judicious use of the piano pedal. The technique of pedaling is as much a physiological thing as are the movements of hand and fingers, and involves coördinations no less fine than many of those analysed in preceding chapters. In studying such phases as tone-qualities and touch-forms, one must bear in mind the possibility of misinterpretation through omission of pedal effects, which play over into key-board technique in so many ways that the relationship of the pedal to the hand- or arm-technique really demands simultaneous study and recording. This soon results in a mass of data, and the experimenter finds it difficult to draw a line between inclusion and exclusion. The pedal records already secured point out numerous subordinate problems, and the ramifications

lead in so many directions that, rather than attempt a partial presentation of the results which the graphic recording of pedal movements has produced, I shall leave the present volume incomplete in the pedal phases, in the belief that, once the data are complete, a separate detailed presentation of the use and function of the piano pedals will better serve the educative purpose.

RESUMÉ

The preceding study clearly shows the need of a revision in some of our pet pedagogic concepts. When Hofmann plays the March from the Ruins of Athens, he does not do so with relaxed arms; when Hutcheson plays the G-sharp minor Etude of Chopin he does not transfer weight from key to key. Relaxation and weight-transfer are the result of an attempt to get away from the fixed hand-position technique of the older Reinecke school. As is so often the case, the pioneers in the movement, in applying a helpful means, went to the other extreme, which their less capable disciples have slavishly followed.

In the foregoing pages is sufficient evidence to show the need for a partial return to the older school: the need for practising finger drill with the arm poised above the keys, that is, without arm-weight. Fortunately, pianists have always, to some extent, played this way, since it is quite impossible mechanically and physiologically to play certain passages otherwise. But I feel quite sure that in the last decade, finger-stroke has not received adequate consideration in piano pedagogy, and that undue stress of relaxation has seriously restricted velocity and technical brilliance.

No less important is the conclusion that the acquisition of pianistic movements is primarily a psychological process. The records have shown, beyond any doubt, that a muscular coördination changes with each change of tempo, intensity, or pitch of the tones. In order, therefore, to exercise the muscles used in the actual movement, we should, from the beginning, have to practise each passage at the tempo, intensity, and pitch at which it is finally to be played. The practical impossibility of doing this does not invalidate the statement; the fact remains that, as soon as we change any of the three factors, the muscular reaction changes. The records given in the preceding chapters, furnish for the first time, so far as I know, actual proof of this variation, and thus demonstrate the uselessness of so-called mechanical practice. Included here are all the various mechanical or silent keyboards. If the nature of the muscular movement is determined by the tonal effect desired—and of this there can no longer be any doubt—the absence of this tonal effect, or its inadequate image, deprives the organism of the chief determinant of the muscular coördination. We do not move our muscles

because we know which muscle contracts, but because we give the muscles an aim: the moving of the hand to a specific point, or the production of a specific tone. Consequently, the value of slow practice, of phrase practice, practising of each hand separately, later addition of pedal, in fact all the forms differing from the form in which the piece is finally to be played, must be sought in the psychological field. Electrical stimulation has shown that, muscularly and mechanically, the normal infant is as ready to play a rapid five finger sequence as is the trained adult: the difference is in the ability to tell the fingers in advance what to do; that is to say the difference is one of experience, of learning. This must not be understood as eliminating the important individual differences, for these exist in the learning process as well as in the retentiveness of the neuro-muscular system.

The study shows, further, how a knowledge of the fundamental principles of mechanics and of muscular action can be of value to the piano teacher. Knowing the location of a muscle and its various angles of pull will readily prevent the assignment of impossible mechanical conditions; it will make possible correct muscular drill; it will aid in distinguishing normal muscular fatigue from the fatigue of incoördination; and it will economize in practice time and method. In short, it substitutes cause for effect and has a value for the piano teacher much the same as that of knowing the cause of a pathological condition has for the doctor.

I recall, particularly, two instances where pupils had worked for several months trying to get "tonal strength with a perfectly relaxed arm". Naturally, they could not succeed. The need for fixation during tone-production was pointed out to them and within a single lesson period the teacher was satisfied. Such cases, unfortunately, are of daily occurrence. Very often the necessary mechanical analysis is never made and the pupils continue day after day in their attempts to do the mechanically impossible, until the hopelessness of the task and the ensuing loss of interest turn them from their task into non-musical activities. Whereupon the teacher (?) attributes it to a lack of talent, or poor studentship.

The experimental procedure adopted in the present study shows, too, the need for getting away from the mere subjective reaction of the teacher or pupil by using the graphic recording method. In a field where emotional colouring and imagination play legitimate and important rôles, the physical and physiological bases can be separated only by eliminating the psychological factors. This discrimination explains the differences between the conclusions reached in the preceding chapters and the generally accepted

statements of the musician. How the former lead into the latter, why the physiological facts are transformed into the colourful psychological effects is the next step in the investigation.

Here we reach an interesting and formidable array of new problems. How does the imagination turn the mechanics of the piano into variegated pictures ? How does the direction of the attention influence the performance of a passage ? Is the whole or part method of practice better ? Should both hands be practised from the beginning ? When should pedal be added ? Should the ear or the eye or neither come first ? How can memory be improved ? What will give the public performer more assurance ? What is the best length of practice period ? How far apart should practice periods be ? Is supervised practice always desirable ?

The list could readily be extended. And these are questions which, I dare say, even the teacher to whom " all theory is grey " would like to have answered.

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THE selection of a representative bibliography from the hundreds of books, monographs and articles which one must wade through in a study of this kind, before the essentials can be separated from the non-essentials, is not an easy task, nor one that can be kept entirely free of significant omissions. The following list is restricted, so far as possible, to the physiological mechanics of the problem. It either omits entirely, or touches but superficially, such associated fields as physiological chemistry, physics, acoustics, construction of the pianoforte, historical analyses, practical schools of technique in the forms of exercises and etudes, pedagogy, the countless articles in the music periodicals, psychological and aesthetic aspects of the problem, and duplications of principles either by the same authors or by their immediate followers.

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